Supplementary Material

Investigating the Impact of Spatial Distribution of Sustainable Drainage System (SuDS) Components on Their Flood Mitigation Performance in Communities with High Groundwater Levels

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Figure S79. Flood map of scenario 22 at the time of 4h (3-hour rainfall event)

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Supplementary materials and methods

S1. Definition of the subcatchments in SWMM

The subcatchment component in SWMM is not completely suitable for this study, so some adjustments need to be made. In SWMM, subcatchments are divided into pervious and impervious subareas. Surface runoff can infiltrate into the upper soil zone of the pervious subarea, but not through the impervious subarea. However, SWMM can only consider the percentage of pervious/impervious subarea in a subcatchment rather than their spatial distribution. Besides, only the average infiltration parameters, slope and Manning roughness coefficient averaged by the area weighting in a subcatchment could be considered, which is not sufficient. To analyze the impact of the spatial distribution of SuDS components, the smaller subcatchments for analysis should be defined with a more specific approach, which is by the land use map. And these more specifically defined subcatchments will be referred to as “mini-catchments” in this paper.

S2. Process of DSM and DTM data

There are trees in some of the green land mini-catchments, where the average slope calculated by processing DSM data cannot be used to simulate the surface condition well. Because in the DSM data, the tree crown in a green land may cover the real condition of the ground. Therefore, the slope data of the green land mini-catchments is calculated by processing the DTM data, while the DSM data is used to calculate the average slope of the other three kinds of mini-catchment.

Table S1. Parameter settings of subcatchment components in the SWMM model

Parameter	Explanation	Value	Unit
Depending on GIS data			
Area	Area of subcatchment	0.002~0.39	ha
Width	Width of overland flow path (Width =Area/Flow length)	2.69~60.55	m
%Slope	Average surface slope	0.95~446.66	%
The same setting for the mini-catchments of buildings			
%Imperv	Percent of impervious area	100	%
N-Imperv	Manning's n value of impervious areas	0.012	none
N-Perv	Manning's n value of pervious areas	0	none
Dstore-Imperv	Depression storage of impervious areas	2.54	mm
Dstore-Perv	Depression storage of pervious areas	0	mm
%Zero-Imperv	Proportion of impervious areas with no depression storage	0	%
The same setting for the mini-catchments of green land			
%Imperv	See above	0	%
N-Imperv	See above	0	none
N-Perv	See above	0.389	none
Dstore-Imperv	See above	0	mm
Dstore-Perv	See above	5.08	mm
%Zero-Imperv	See above	0	%
The same setting for the mini-catchments of open space			
%Imperv	See above	100	%
N-Imperv	See above	0.011	none
N-Perv	See above	0	none
Dstore-Imperv	See above	2.54	mm
Dstore-Perv	See above	0	mm
%Zero-Imperv	See above	0	%
The same setting for the mini-catchments of roads			
%Imperv	See above	100	%
N-Imperv	See above	0.011	none
N-Perv	See above	0	none
Dstore-Imperv	See above	2.54	mm
Dstore-Perv	See above	0	mm
%Zero-Imperv	See above	0	%

Table S2. Infiltration parameter settings in the SWMM model

Parameter	Explanation	Value	Unit
The infiltration setting for the mini-catchments of buildings			
Max. Infil. Rate	Maximum rate on the Horton infiltration curve	0	mm/hr
Min. Infil. Rate	Minimum rate on the Horton infiltration curve	0	mm/hr
Decay Const.	Decay constant for the Horton infiltration curve	1.00	1/hr
Drying Time	Time for a fully saturated soil to completely dry	7.00	days
The infiltration setting for the mini-catchments of green land			
Max. Infil. Rate	See above	15	mm/hr
Min. Infil. Rate	See above	3.302	mm/hr
Decay Const.	See above	1.00	1/hr
Drying Time	See above	7.00	days
The infiltration setting for the mini-catchments of open space			
Max. Infil. Rate	See above	0.00835	mm/hr
Min. Infil. Rate	See above	0	mm/hr
Decay Const.	See above	1.00	1/hr
Drying Time	See above	7.00	days
The infiltration setting for the mini-catchments of roads			
Max. Infil. Rate	See above	0.00835	mm/hr
Min. Infil. Rate	See above	0	mm/hr
Decay Const.	See above	1.00	1/hr
Drying Time	See above	7.00	days

Table S3. Parameter settings of junctions and conduits in the SWMM model

Parameter	Explanation	Value	Unit
Junctions			
Invert El.	Elevation of junction's invert	-6.0~-9.0	m
Max. Depth	Maximum water depth	5.0	m
Initial Depth	Initial water depth in junction	0	m
Surcharge Depth	Depth in excess of maximum depth before flooding occurs	0	m
Ponded Area	Area of ponded water when flooded	100.0	m^2
Conduits			
Shape	Geometric properties of the conduit's cross section	circular	none
Roughness	Manning's roughness coefficient	0.015	none
Max. Depth	Diameter of circular conduit	2.0	m
Inlet Offset	Depth or elevation of the conduit invert above the node invert at the upstream end of the conduit	3.0	m
Outlet Offset	Depth or elevation of the conduit invert above the node invert at the downstream end of the conduit	3.0	m
Length	Conduit length	14.88~243.56	m
Initial Flow	Initial flow in the conduit	0	m^3/s

The assumption parameters are set according to a previous study on the spatial distribution of pervious pavements and bioretention cells in a community-scale catchment of 20 hectares[35]. The diameter of circular conduits used in their study is 1.2 meters[35]. Therefore, considering that the study area in this study is bigger and there are fewer conduits set in the study area, the diameter of the conduits is set as 2 meters. And from the same consideration, the maximum water depth of junctions is set as 5 meters, referring to the depth of 3.8 meters set in the previous similar study[35].

Table S4. Parameter settings of the SuDS components in the SWMM model

Layers	Coefficient	Green roof	Rain garden	Unit
Surface	Berm height	0	150	mm
	Vegetation volume fraction	0.1	0.1	volume fraction
	Surface roughness	0.15	0.41	none
	Surface slope	5	1	%
Soil	Thickness	120	450	mm
	Porosity	0.437	0.437	volume fraction
	Field capacity	0.105	0.105	volume fraction
	Wilting point	0.047	0.047	volume fraction
	Conductivity	25.4	25.4	mm/hr
	Conductivity slope	55.4	55.4	none
	Suction head	60.96	60.96	mm
Drainage mat	Thickness	25.4	/	mm
	void fraction	0.5	/	none
	roughness/Manning's n	0.25	/	none

The berm height of green roofs is set as 0 meters to avoid ponding on the roof, while the berm height of rain gardens is set as 150mm according to the maximum water depth regulated in the SuDS manual [25]. The vegetation volume faction of both green roofs and rain gardens is set as 0.1 refer to the recommended value for surface with dense vegetations in the SWWM user's manual [57]. According to the SuDS manual [25], the vegetations in green roofs and rain gardens are chosen as short grass and Bermuda grass, respectively. Then the surface roughness of green roofs and rain gardens are set as 0.15 and 0.41 according to Manning's n summarized in Table S5. And the surface slope of green roofs and rain gardens are both set according to the SuDS manual too [25]. The thickness of soil layer is set according to the recommendation in the SWMM user's manual [57]. As the loamy soil is chosen as the soil used in the soil layer of both SuDS components to increase the infiltration, the rest of six soil layer parameters are set according to Table S6. The thickness, void fraction and roughness of drainage mat in green roofs are set according to the recommendation range of value provided in the SWMM user's manual [57].

Table S5. Summary of soil characteristics in the SWMM user's manual [57]

Soil texture class	Porosity (fraction)
Sand	0.437
Loamy sand	0.437
Sandy loam	0.453
Loam	0.463
Silt loam	0.501
Sandy clay loam	0.398
Clay loam	0.464
Silty clay loam	0.471
Sandy clay	0.430
Silty clay	0.479
Clay	0.475

Table S6. Summary of Manning's n in the SWMM user's manual [57]

Surface	**n**
Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipes	0.024
Cement rubble surface	0.024
Fallow soils (no residue)	0.050
Cultivated soils (residue cover < 20%)	0.060
Cultivated soils (residue cover > 20%)	0.170
Range (natural)	0.130
Grass (short, prairie)	0.150
Grass (dense)	0.240
Grass (Bermuda grass)	0.410
Woods (light underbrush)	0.400
Woods (dense underbrush)	0.800

Table S7. Summary of types and number of SuDS components applied in the 27 scenarios

Scenarios	Green roof units	Rain garden units	Total SuDS units
1	622	527	1149
2	622	527	1149
3	622	527	1149
4	622	527	1149
5	622	527	1149
6	622	527	1149
7	622	527	1149
8	622	527	1149
9	622	527	1149
10	622	527	1149
11	622	527	1149
12	622	527	1149
13	622	527	1149
14	622	527	1149
15	622	527	1149
16	622	527	1149
17	622	527	1149
18	622	527	1149
19	622	341	963
20	622	341	963
21	622	341	963
22	622	341	963
23	622	341	963
24	622	341	963
25	622	341	963
26	622	341	963
27	622	341	963

Table S8. Summary of the spatial characteristics in the considered scenarios

Scenarios	Connectedness (%)	Flow distance (m)	GR Edge density (m/m^2)	RG Edge density (m/m^2)
1	0.000	81.392	0.364	0.275
2	0.026	81.392	0.364	0.275
3	0.045	81.392	0.364	0.275
4	0.063	81.392	0.364	0.275
5	0.085	81.392	0.364	0.275
6	0.099	81.392	0.364	0.275
7	0.111	81.392	0.364	0.275
8	0.124	81.392	0.364	0.275
9	0.141	81.392	0.364	0.275
10	0.141	84.832	0.260	0.170
11	0.141	90.676	0.319	0.170
12	0.141	83.597	0.343	0.170
13	0.141	79.287	0.352	0.170
14	0.141	79.947	0.364	0.170
15	0.141	97.768	0.260	0.243
16	0.141	85.409	0.260	0.271
17	0.141	82.589	0.260	0.274
18	0.141	83.459	0.260	0.275
19	0.141	83.179	0.364	0.264
20	0.141	82.703	0.364	0.263
21	0.141	82.281	0.364	0.263
22	0.141	82.016	0.364	0.263
23	0.141	82.505	0.364	0.267
24	0.141	81.512	0.364	0.266
25	0.141	81.636	0.364	0.266
26	0.141	81.598	0.364	0.266
27	0.141	81.449	0.364	0.266

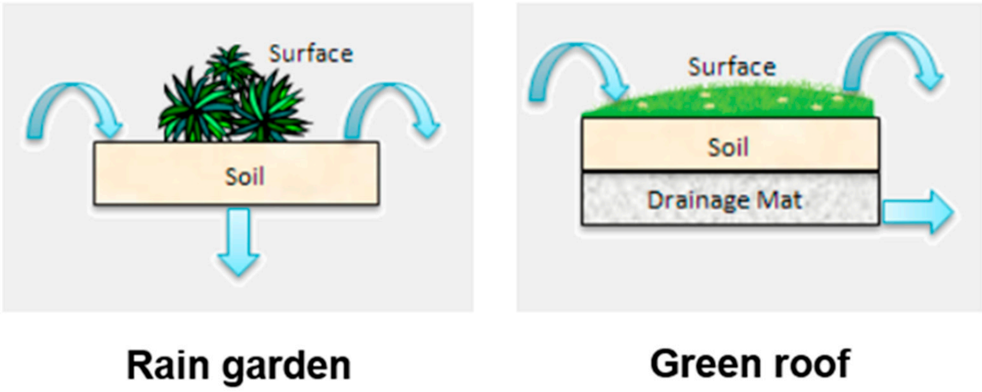

Fig. S1. Schematic diagram of the rain garden and green roof[51]

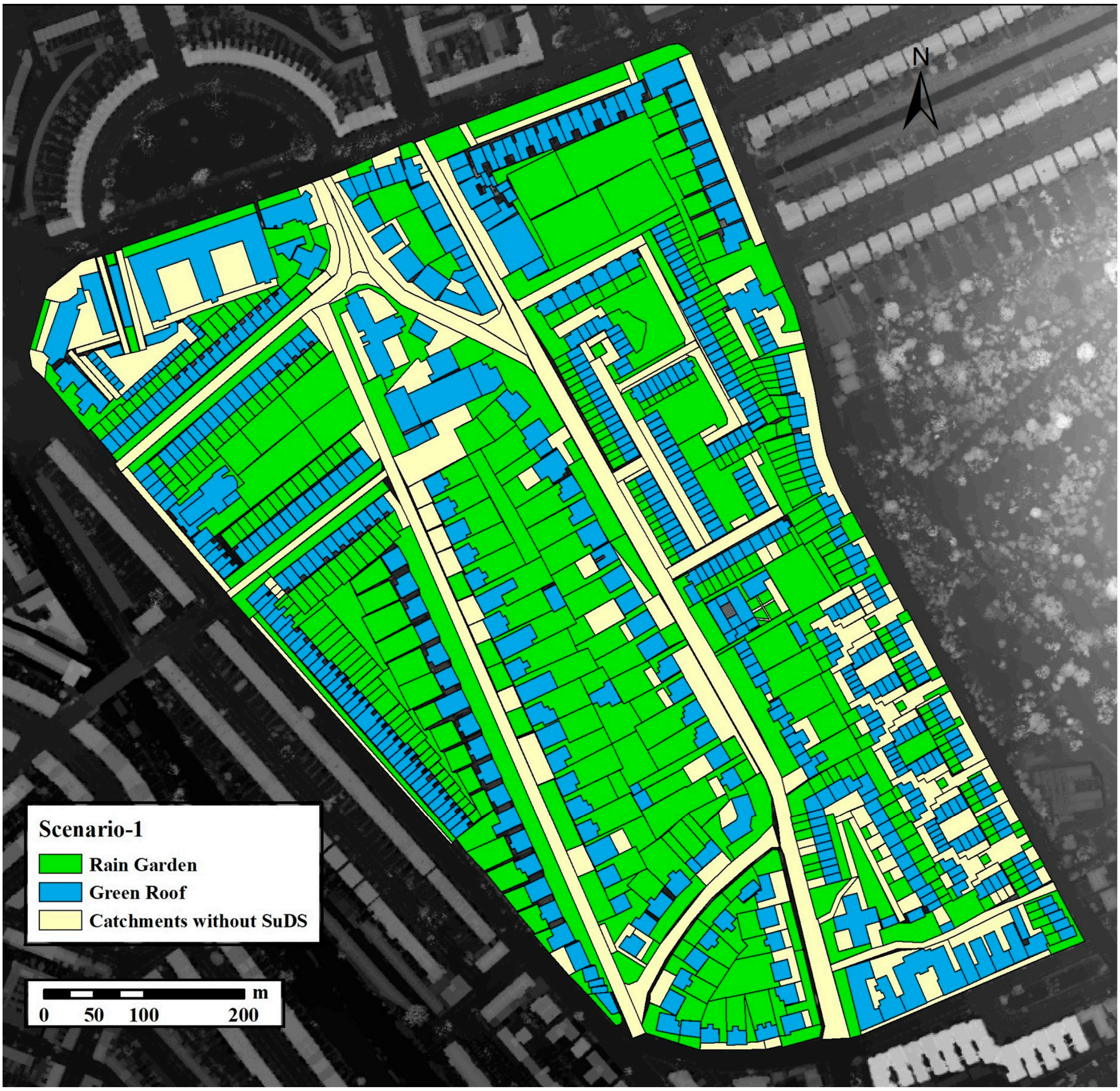

Fig. S2. The sketch map of Scenario 1

Scenario 1: One rain garden unit is applied on every mini-catchment of green land and one green roof unit is applied to each mini-catchment of buildings; no water transportation between SuDS components exists; no clustered SuDS component exists.

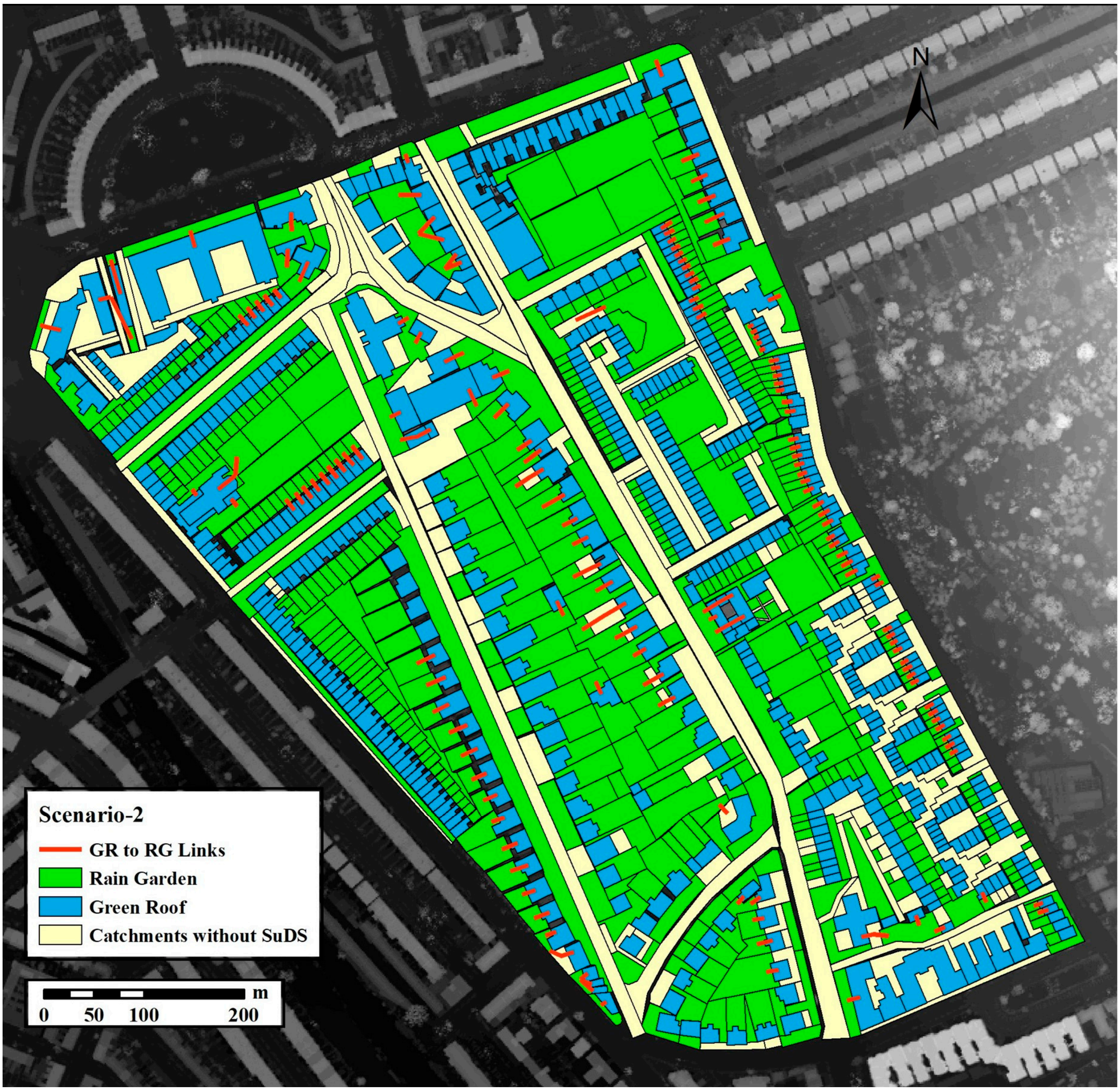

Fig. S3. The sketch map of Scenario 2

Scenario 2: One rain garden unit is applied on every mini-catchment of green land and one green roof unit is applied to each mini-catchment of buildings; the runoff from 151 green roofs is drained to nearby rain gardens; no clustered SuDS component exists.

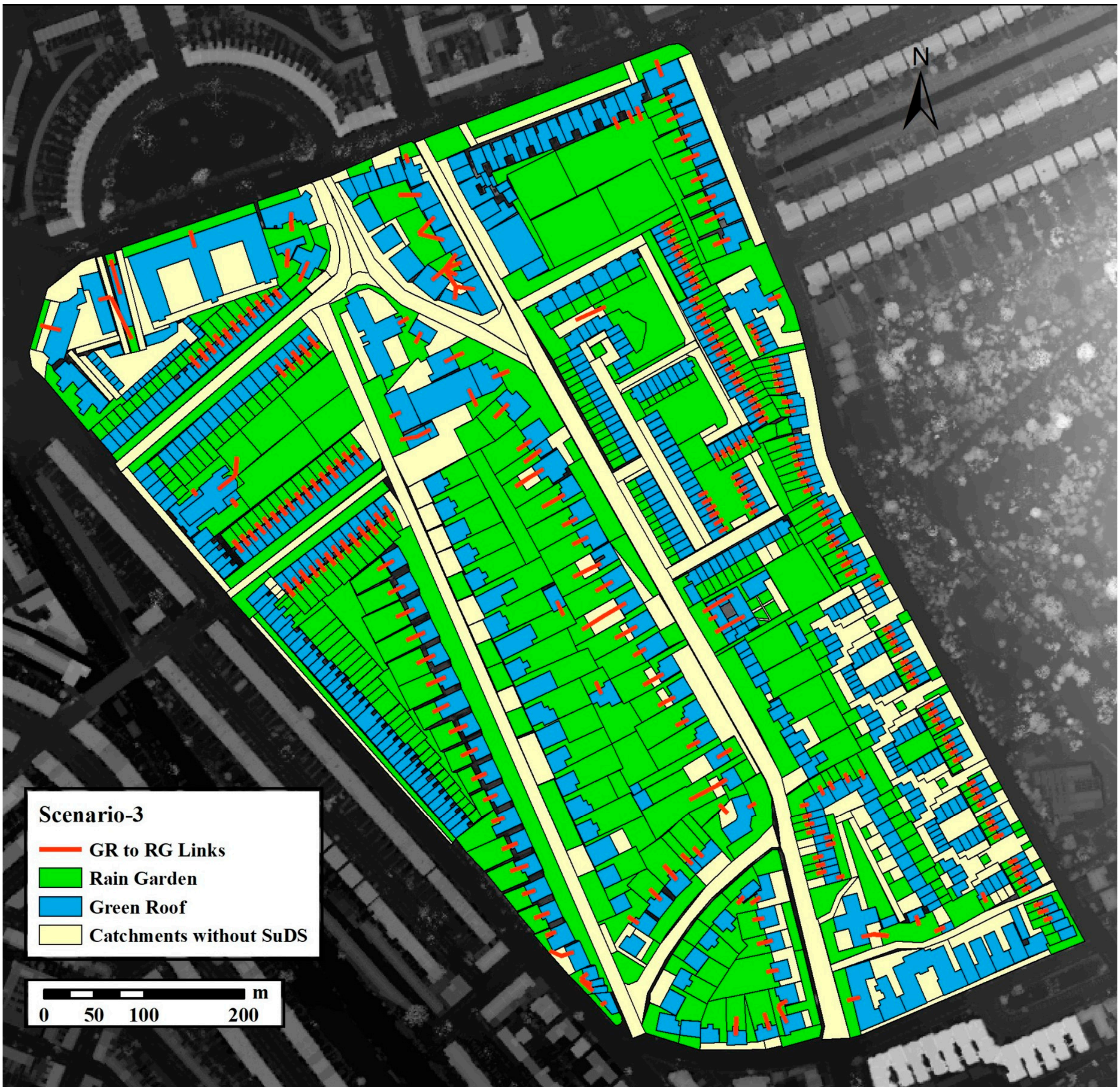

Fig. S4. The sketch map of Scenario 3

Scenario 3: One rain garden unit is applied on every mini-catchment of green land and one green roof unit is applied to each mini-catchment of buildings; the runoff from 275 green roofs is drained to nearby rain gardens; no clustered SuDS component exists.

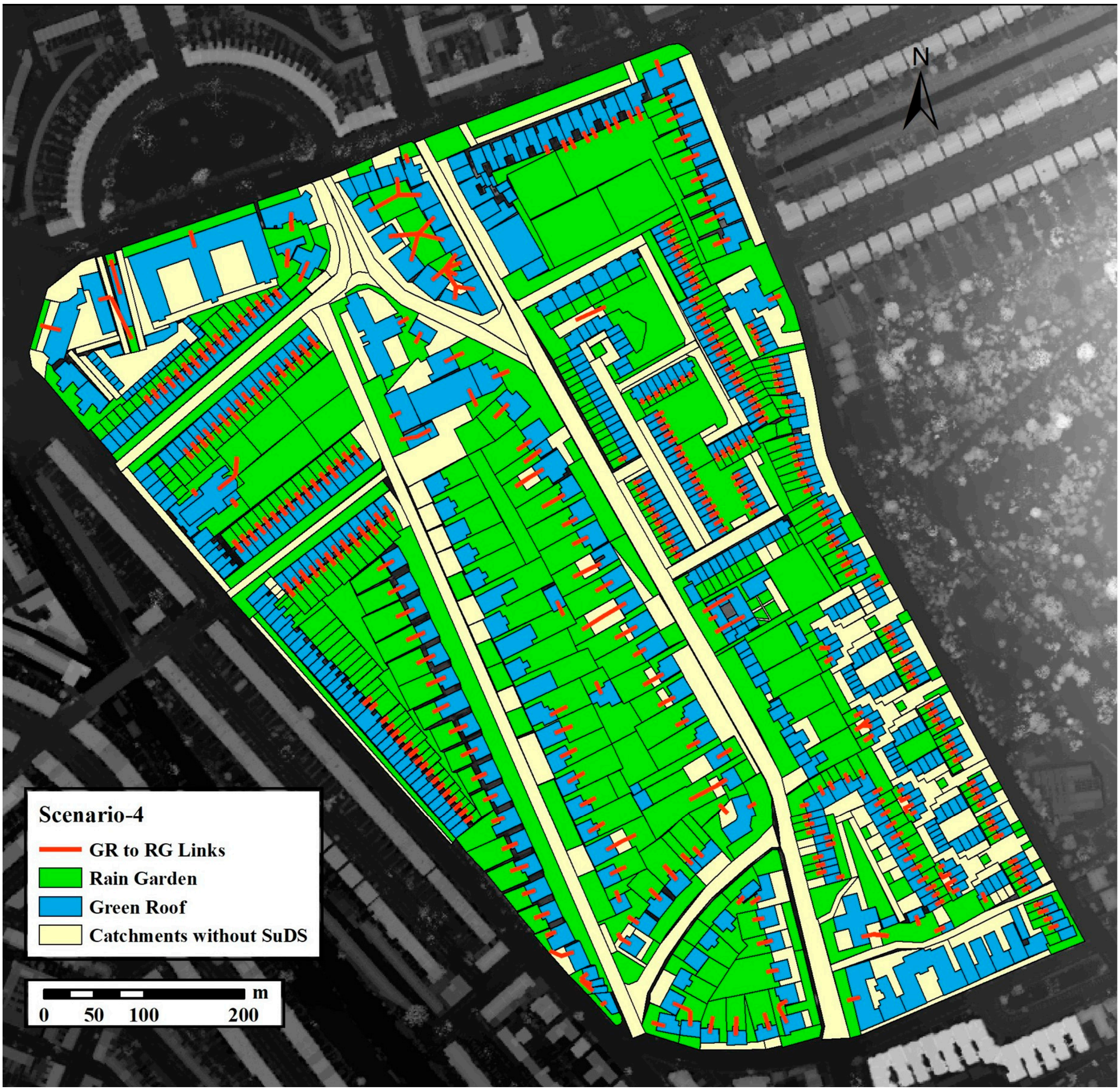

Fig. S5. The sketch map of Scenario 4

Scenario 4: One rain garden unit is applied on every mini-catchment of green land and one green roof unit is applied to each mini-catchment of buildings; the runoff from 395 green roofs is drained to nearby rain gardens; no clustered SuDS component exists.

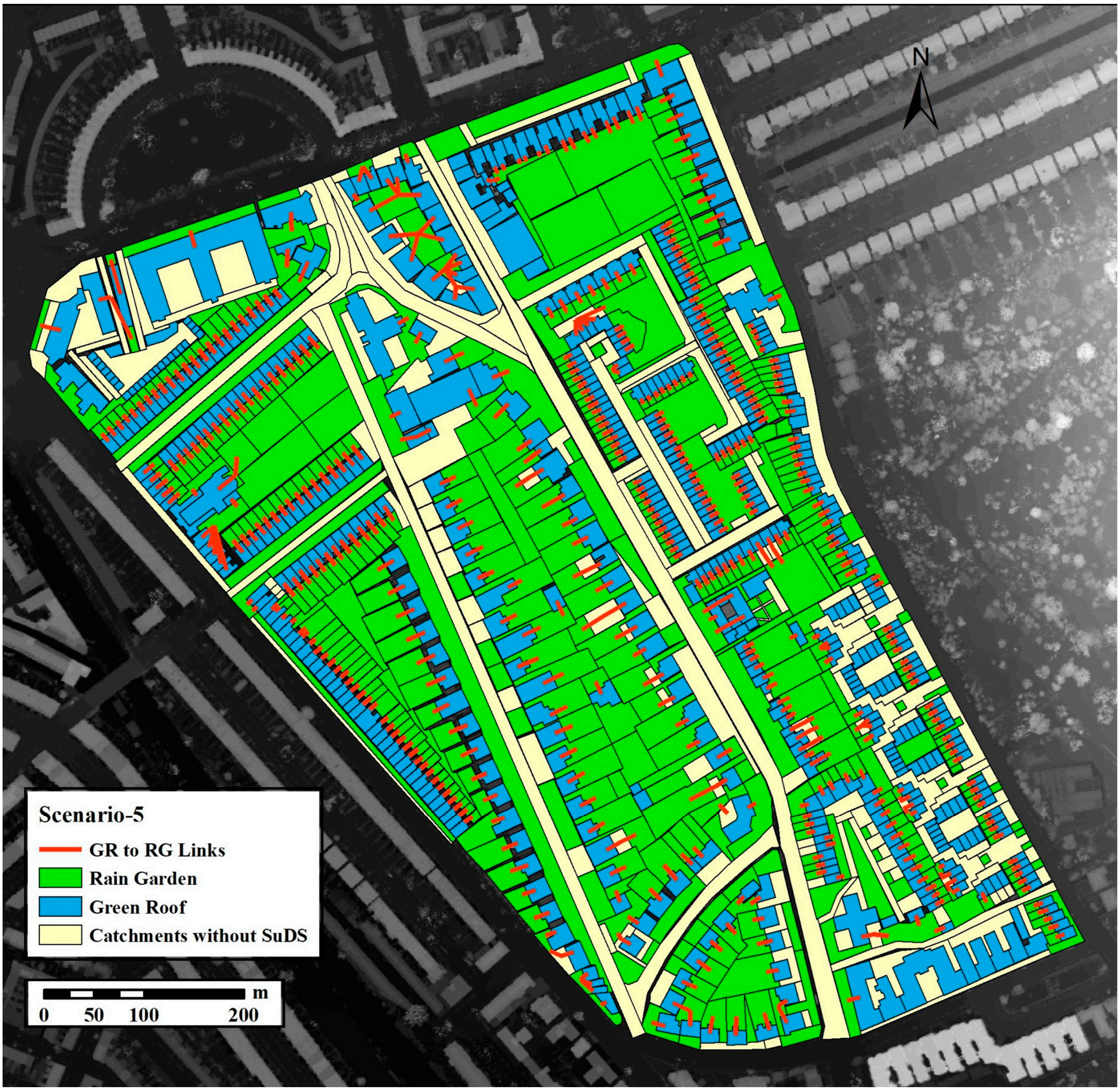

Fig. S6. The sketch map of Scenario 5

Scenario 5: One rain garden unit is applied on every mini-catchment of green land and one green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; no clustered SuDS component exists.

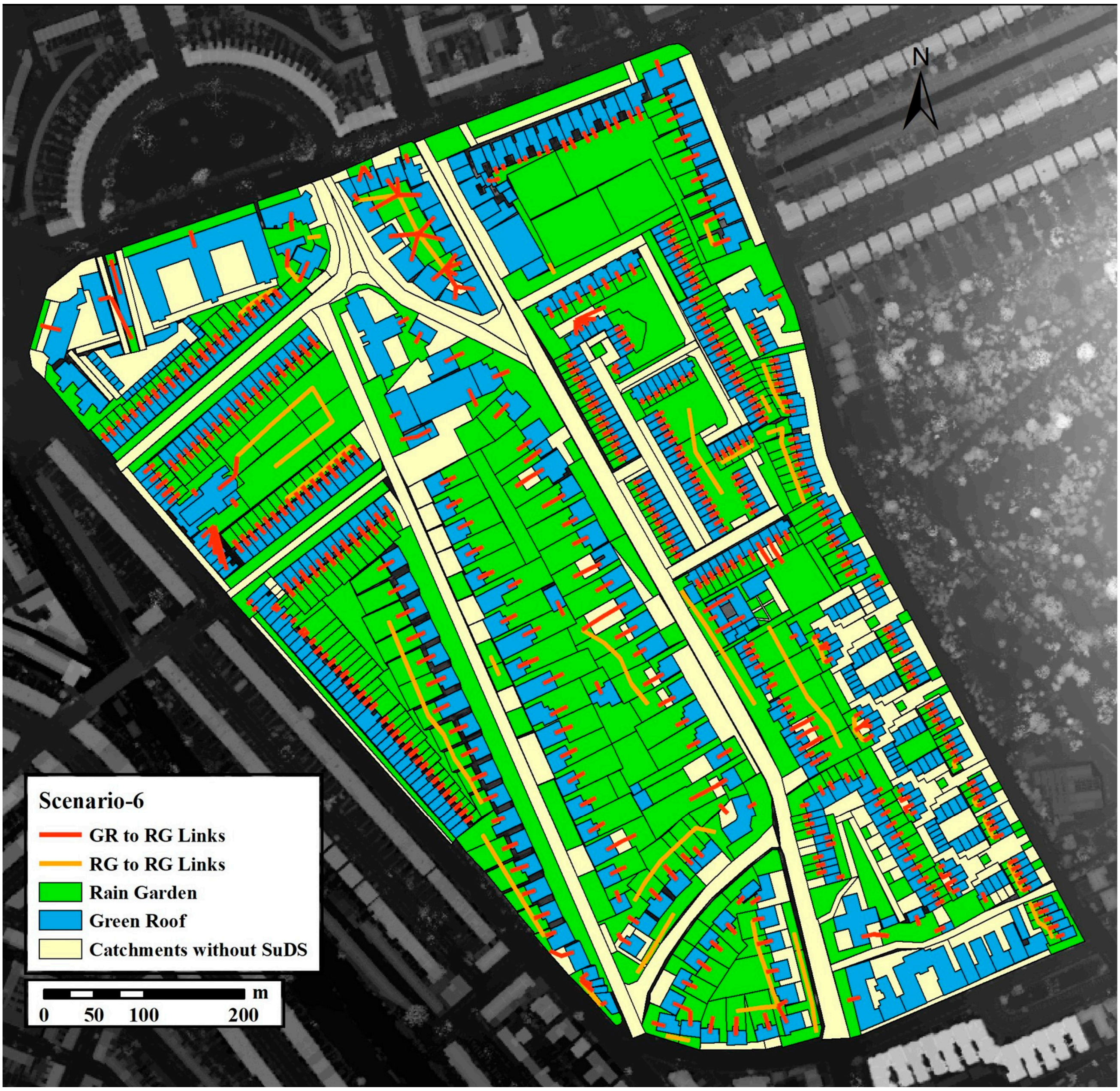

Fig. S7. The sketch map of Scenario 6

Scenario 6: One rain garden unit is applied on every mini-catchment of green land and one green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; the water in 139 adjacent rain gardens flows in one direction to the next in turn; no clustered SuDS component exists.

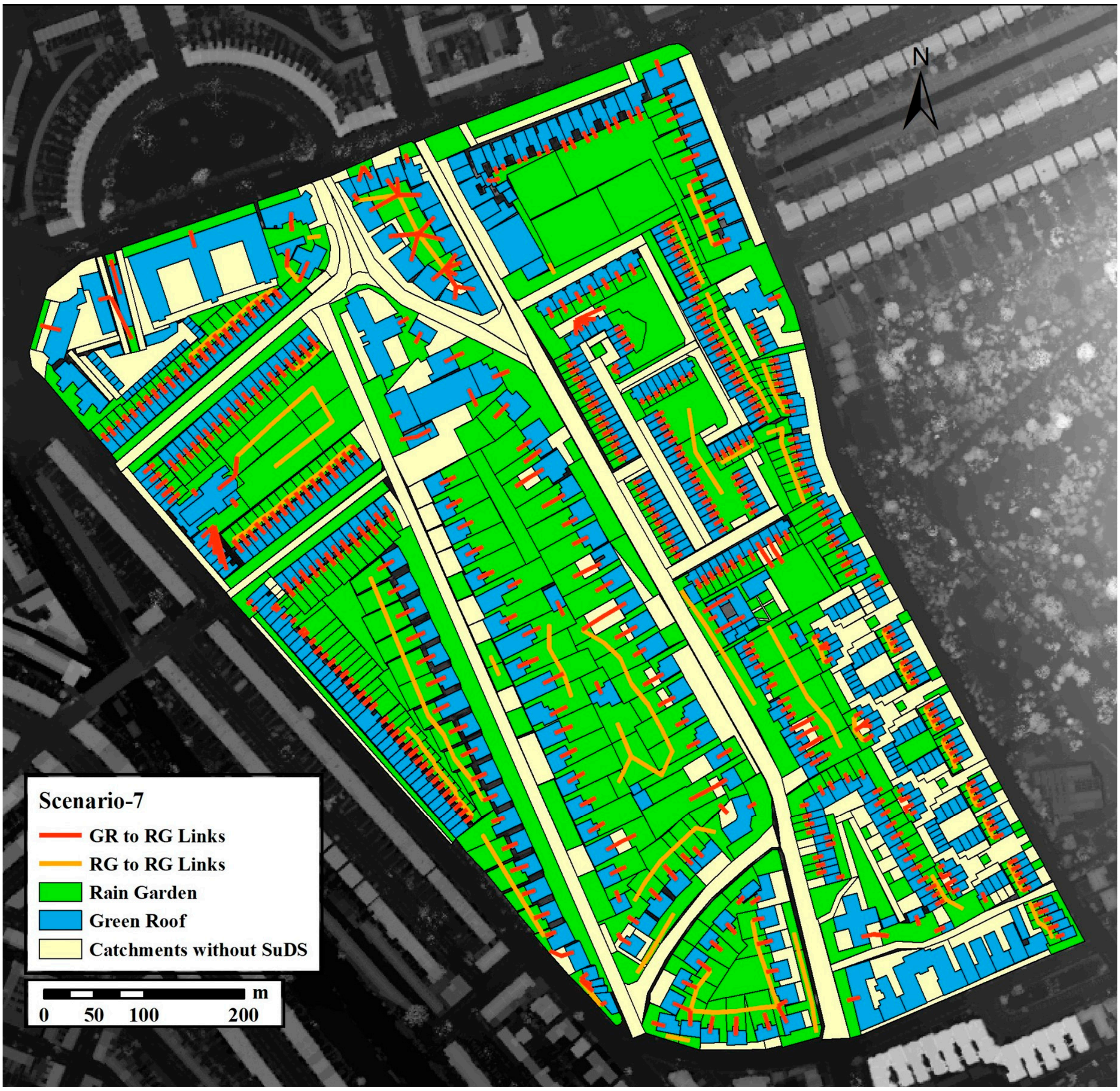

Fig. S8. The sketch map of Scenario 7

Scenario 7: One rain garden unit is applied on every mini-catchment of green land and one green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; the water in 235 adjacent rain gardens flows in one direction to the next in turn; no clustered SuDS component exists.

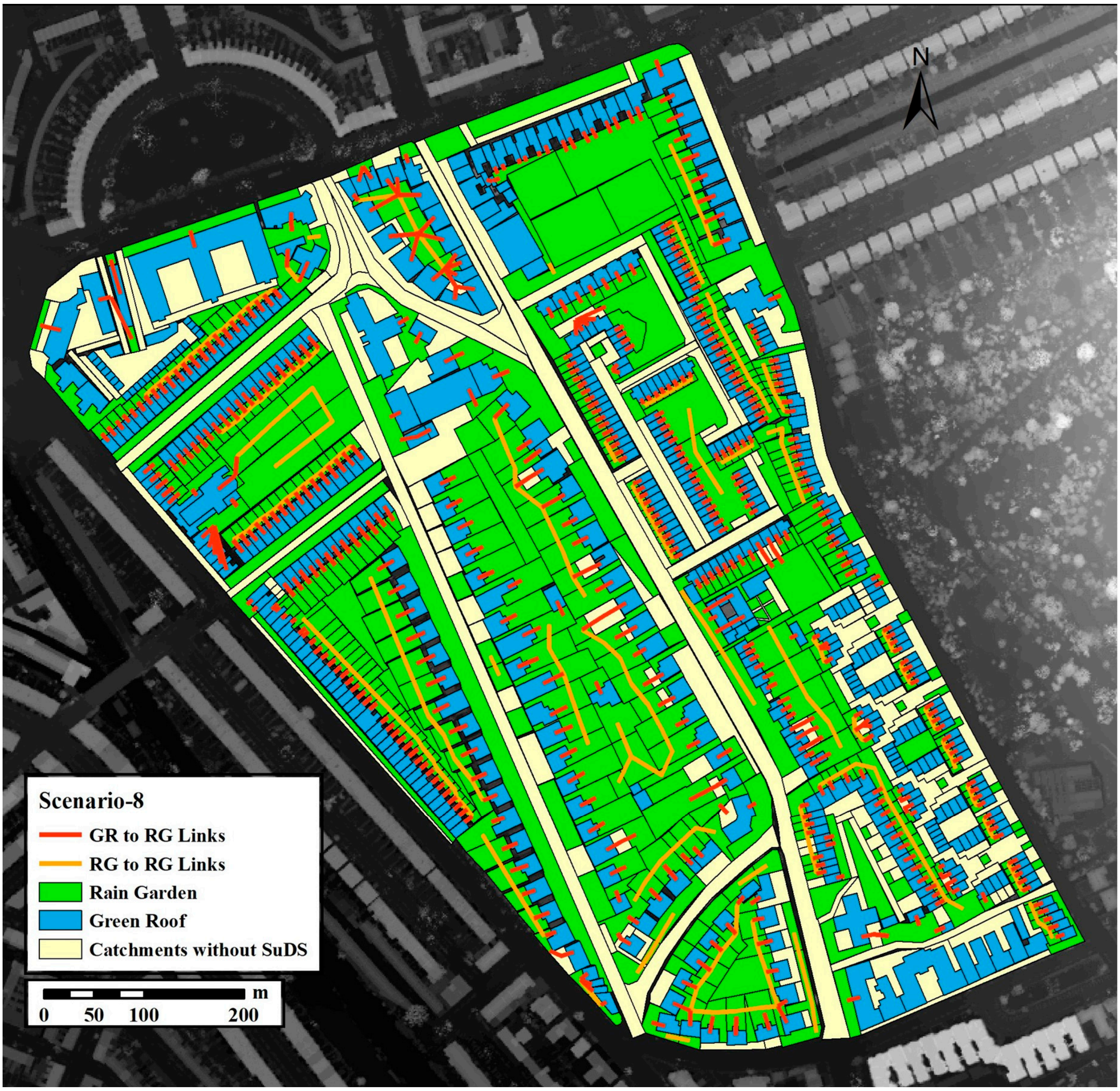

Fig. S9. The sketch map of Scenario 8

Scenario 8: One rain garden unit is applied on every mini-catchment of green land and one green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; the water in 315 adjacent rain gardens flows in one direction to the next in turn; no clustered SuDS component exists.

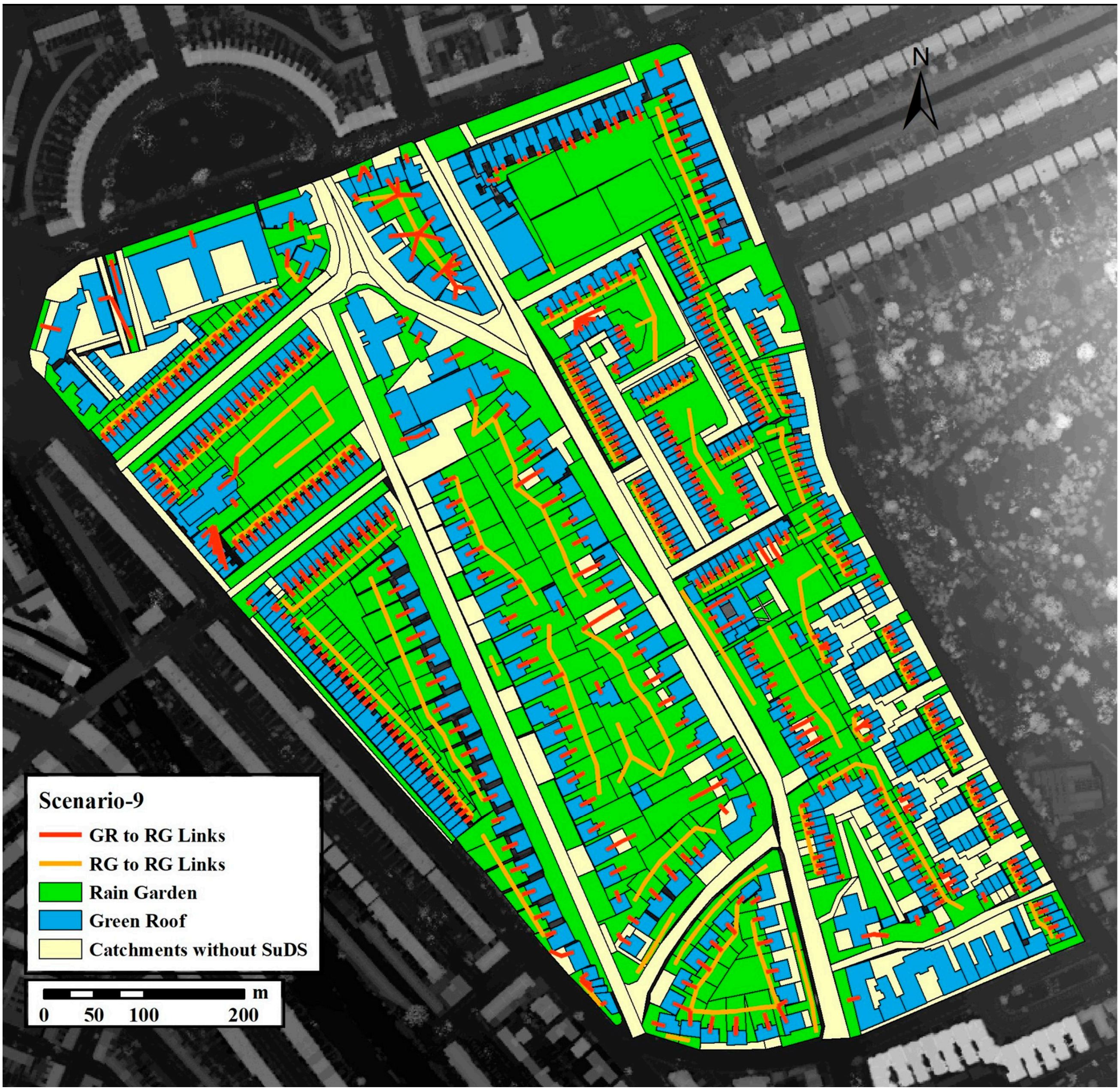

Fig. S10. The sketch map of Scenario 9

Scenario 9: One rain garden unit is applied on every mini-catchment of green land and one green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; the water in 422 adjacent rain gardens flows in one direction to the next in turn; no clustered SuDS component exists.

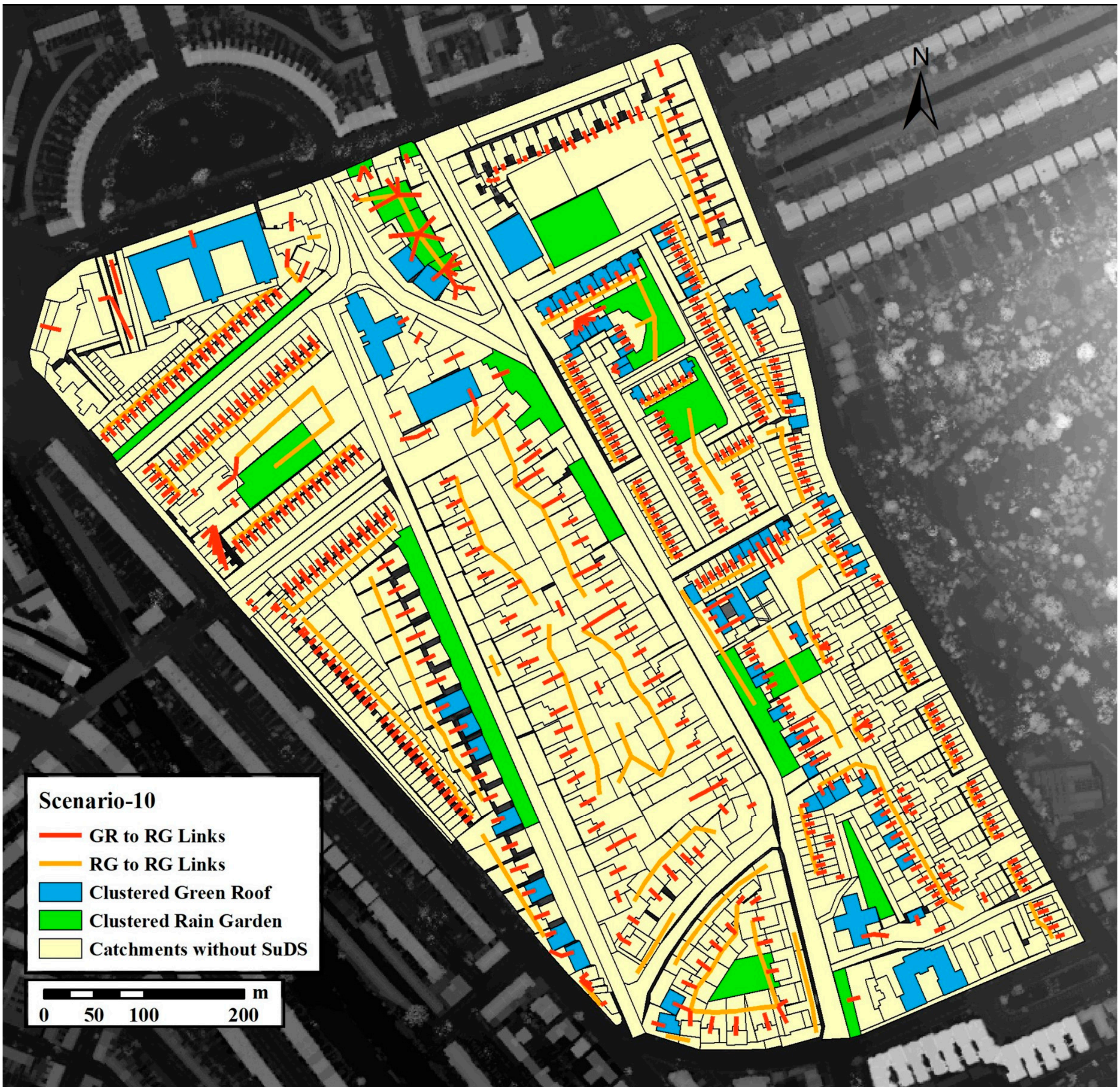

Fig. S11. The sketch map of Scenario 10

Scenario 10: 622 green roofs in each subcatchment are clustered in 69 bigger mini-catchments of buildings, and 527 rain gardens are clustered in 18 bigger mini-catchments of green land; the runoff from 526 building roofs is drained to nearby green land; the water in 422 of the adjacent green land flows in one direction to the next in turn.

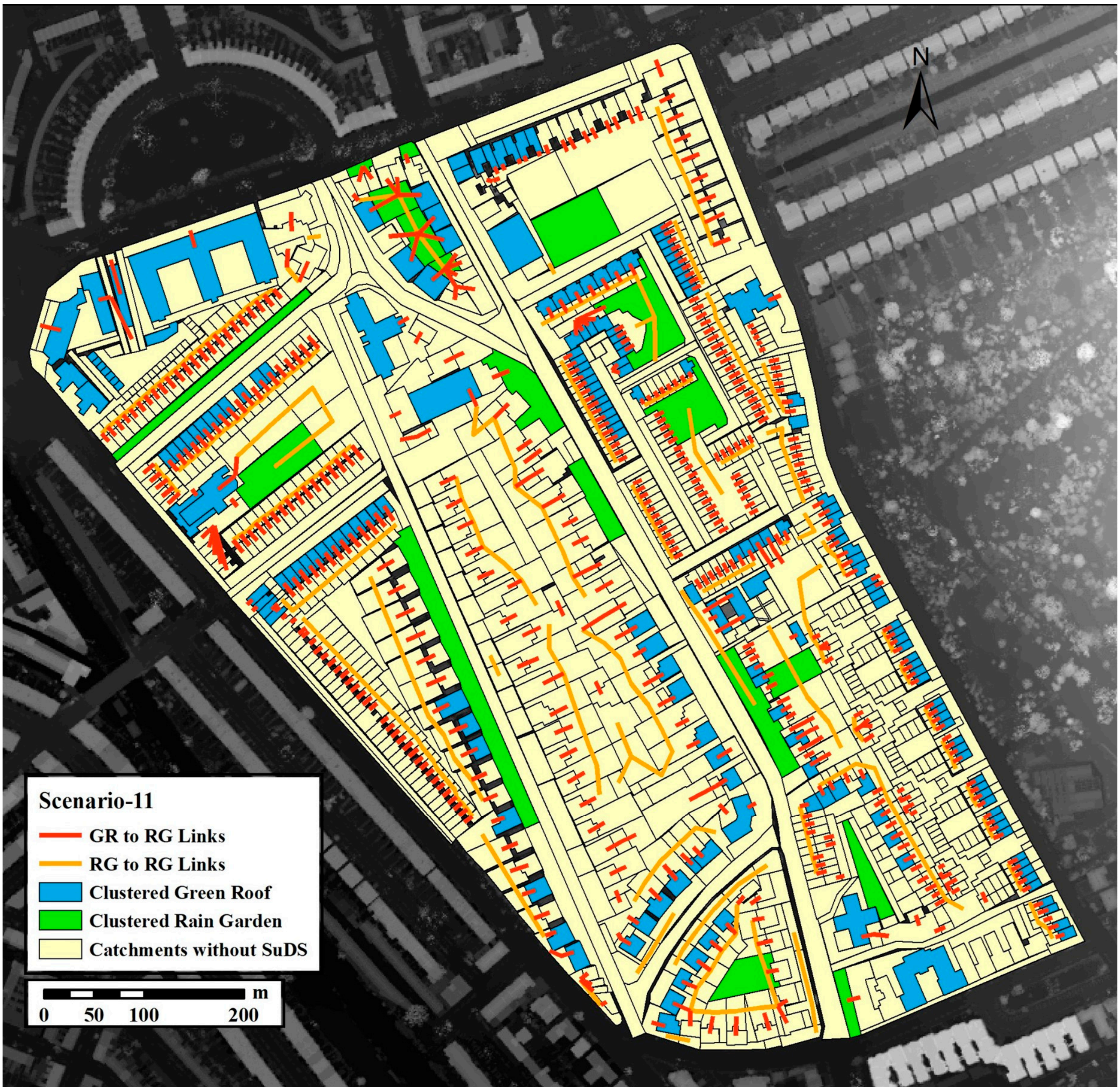

Fig. S12. The sketch map of Scenario 11

Scenario 11: 489 green roofs in each subcatchment are clustered in 69 bigger mini-catchments of buildings, and 527 rain gardens are clustered in 18 bigger mini-catchments of green land; the runoff from 526 building roofs is drained to nearby green land; the water in 422 of the adjacent green land flows in one direction to the next in turn.

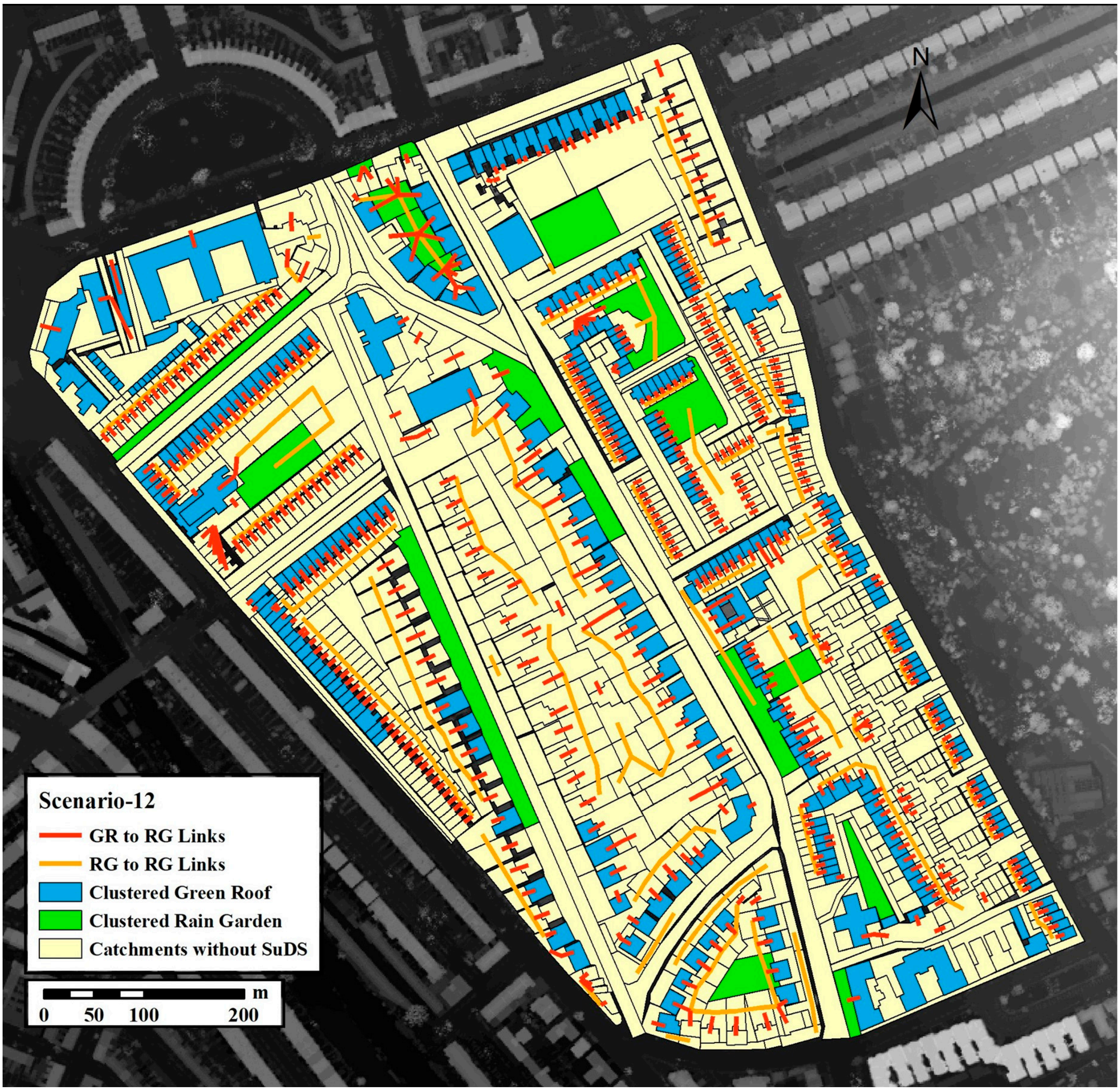

Fig. S13. The sketch map of Scenario 12

Scenario 12: 355 green roofs in each subcatchment are clustered in 69 bigger mini-catchments of buildings, and 527 rain gardens are clustered in 18 bigger mini-catchments of green land; the runoff from 526 building roofs is drained to nearby green land; the water in 422 of the adjacent green land flows in one direction to the next in turn.

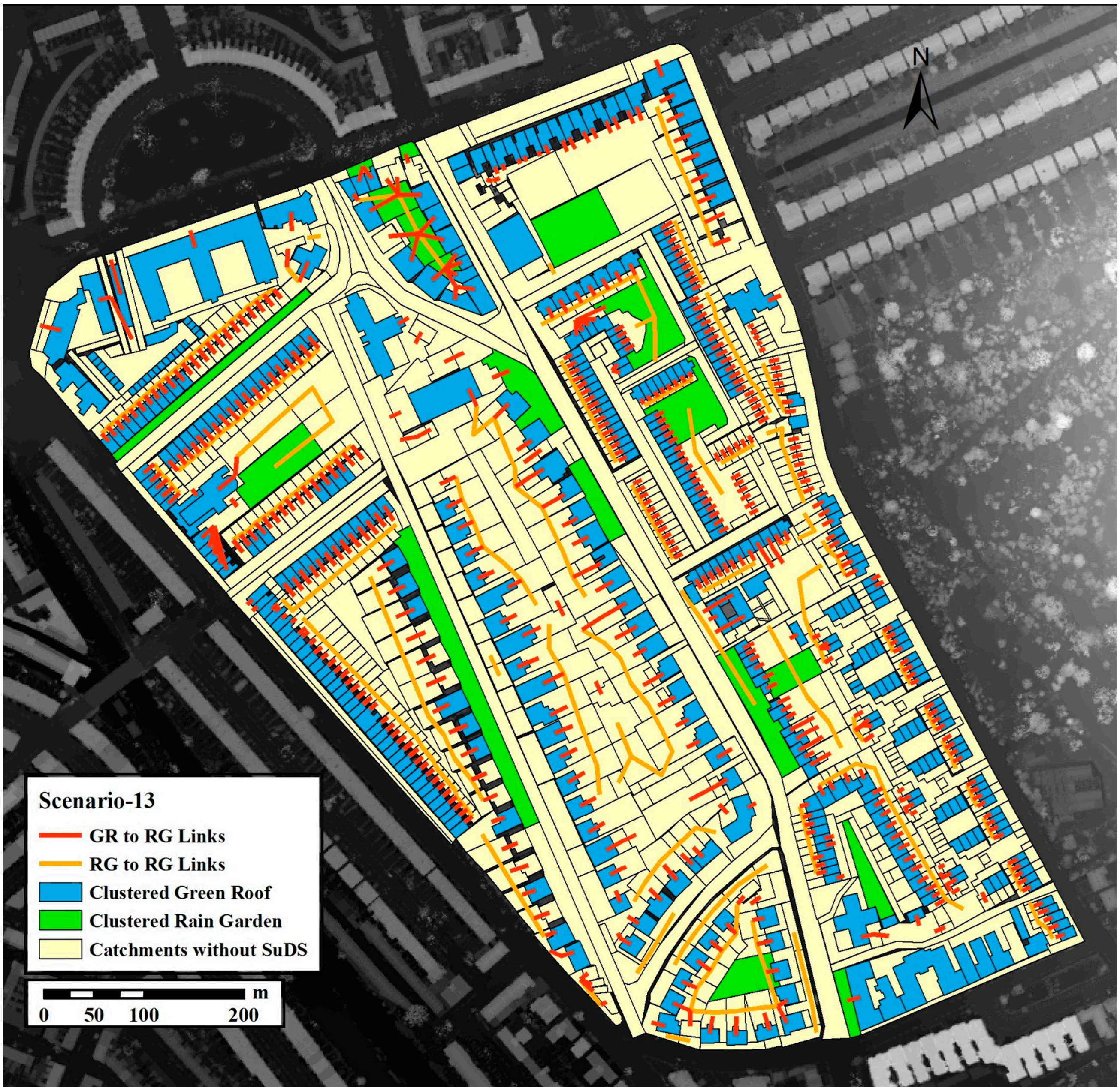

Fig. S14. The sketch map of Scenario 13

Scenario 13: 214 green roofs in each subcatchment are clustered in 69 bigger mini-catchments of buildings, and 527 rain gardens are clustered in 18 bigger mini-catchments of green land; the runoff from 526 building roofs is drained to nearby green land; the water in 422 of the adjacent green land flows in one direction to the next in turn.

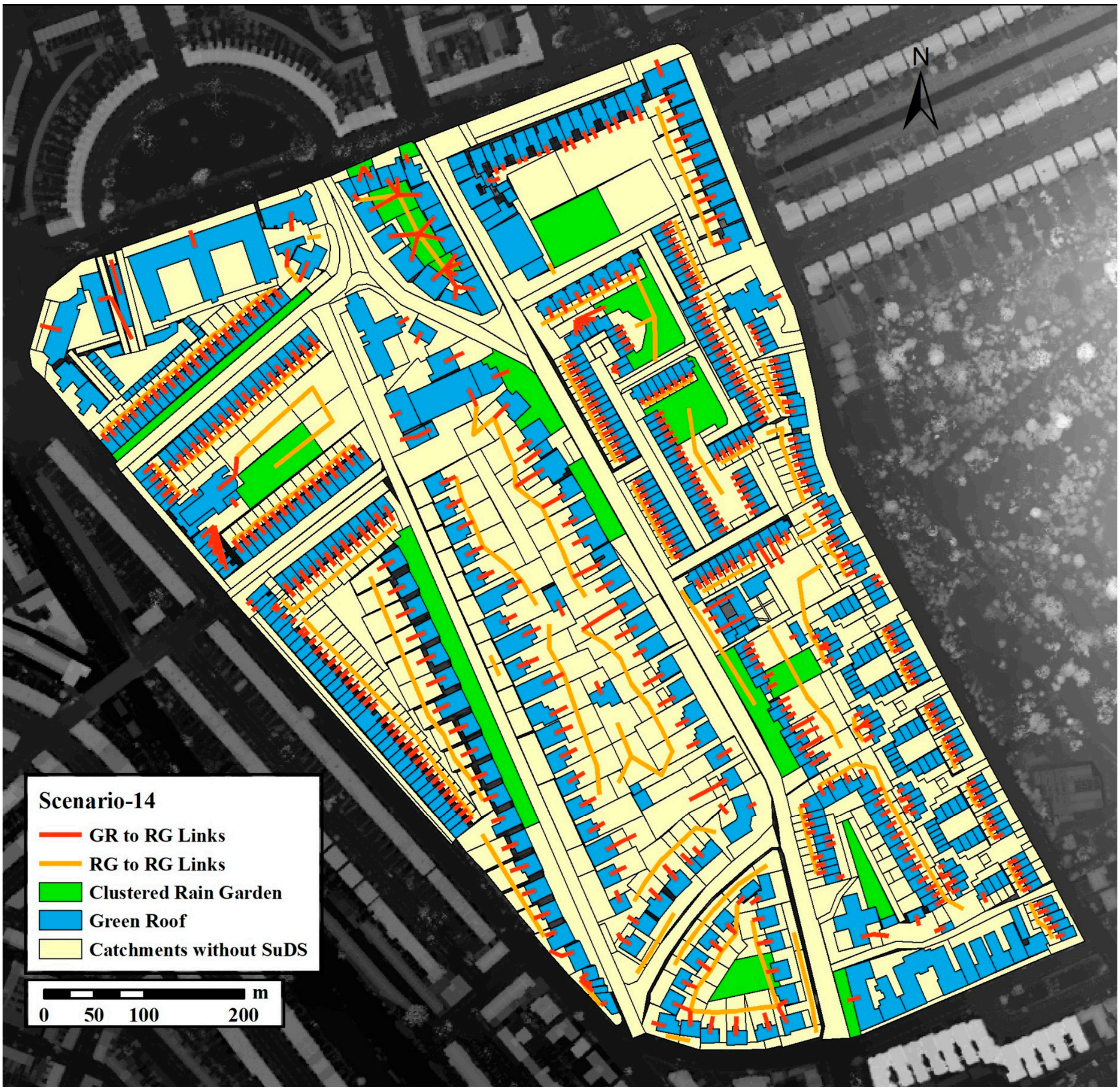

Fig. S15. The sketch map of Scenario 14

Scenario 14: No green roof in each subcatchment is clustered, and 527 rain gardens are clustered in 18 bigger mini-catchments of green land; the runoff from 526 building roofs is drained to nearby green land; the water in 422 of the adjacent green land flows in one direction to the next in turn.

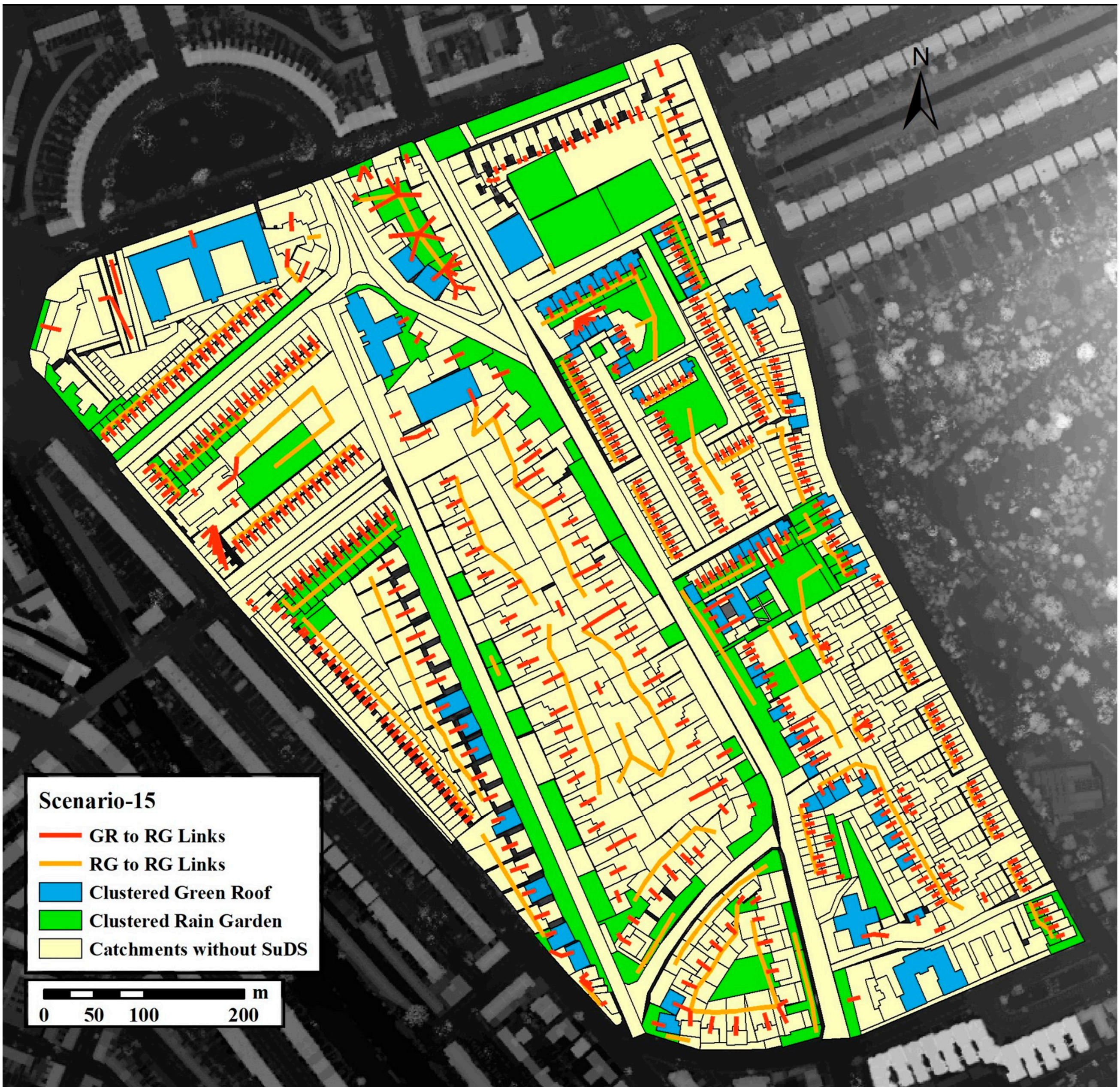

Fig. S16. The sketch map of Scenario 15

Scenario 15: 396 rain gardens in each subcatchment are clustered in 18 bigger mini-catchments of green land, and 622 green roofs are clustered in 69 bigger mini-catchments of buildings; the runoff from 526 building roofs is drained to nearby green land; the water in 422 of the adjacent green land flows in one direction to the next in turn.

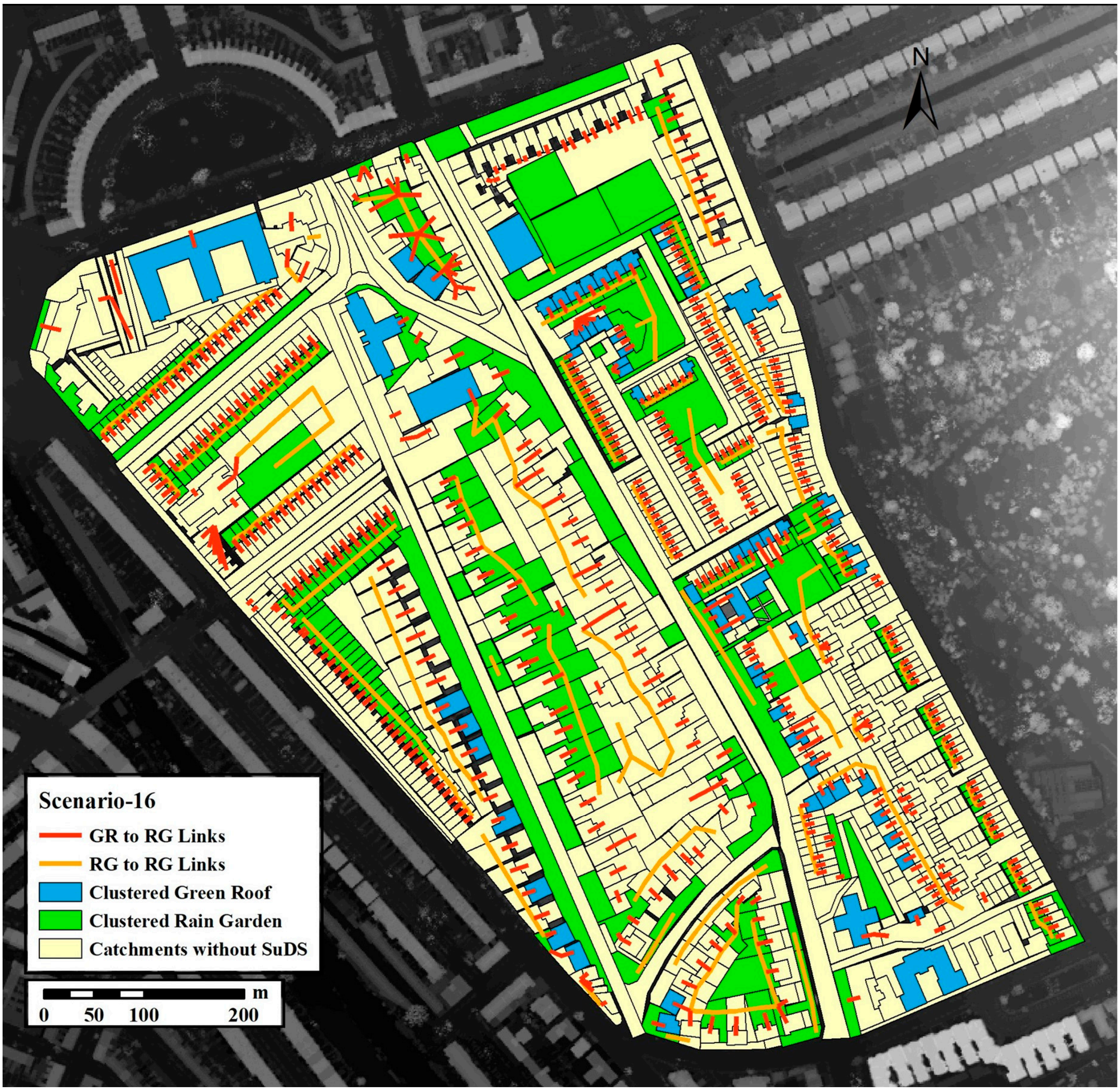

Fig. S17. The sketch map of Scenario 16

Scenario 16: 270 rain gardens in each subcatchment are clustered in 18 bigger mini-catchments of green land, and 622 green roofs are clustered in 69 bigger mini-catchments of buildings; the runoff from 526 building roofs is drained to nearby green land; the water in 422 of the adjacent green land flows in one direction to the next in turn.

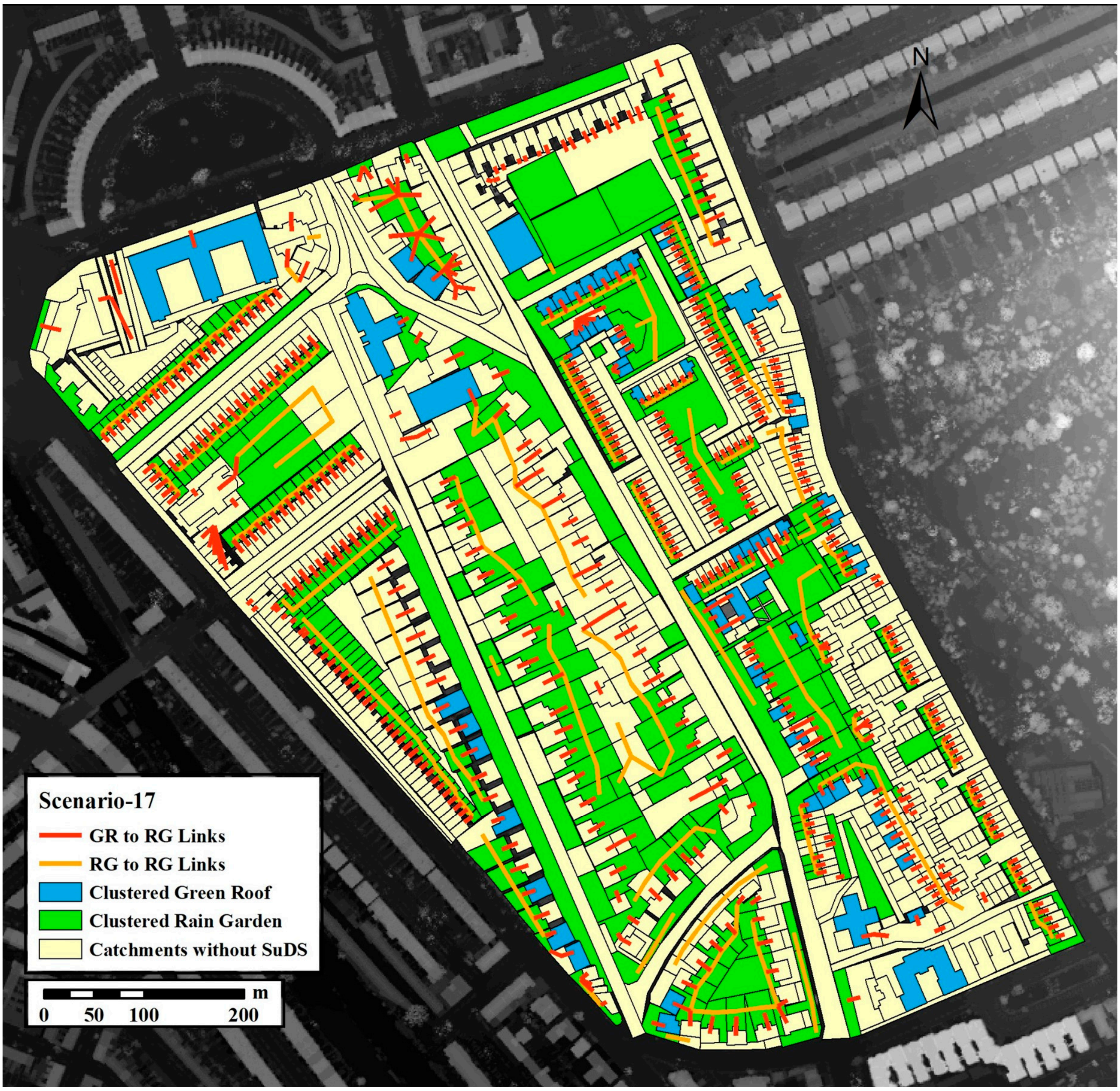

Fig. S18. The sketch map of Scenario 17

Scenario 17: 166 rain gardens in each subcatchment are clustered in 18 bigger mini-catchments of green land, and 622 green roofs are clustered in 69 bigger mini-catchments of buildings; the runoff from 526 building roofs is drained to nearby green land; the water in 422 of the adjacent green land flows in one direction to the next in turn.

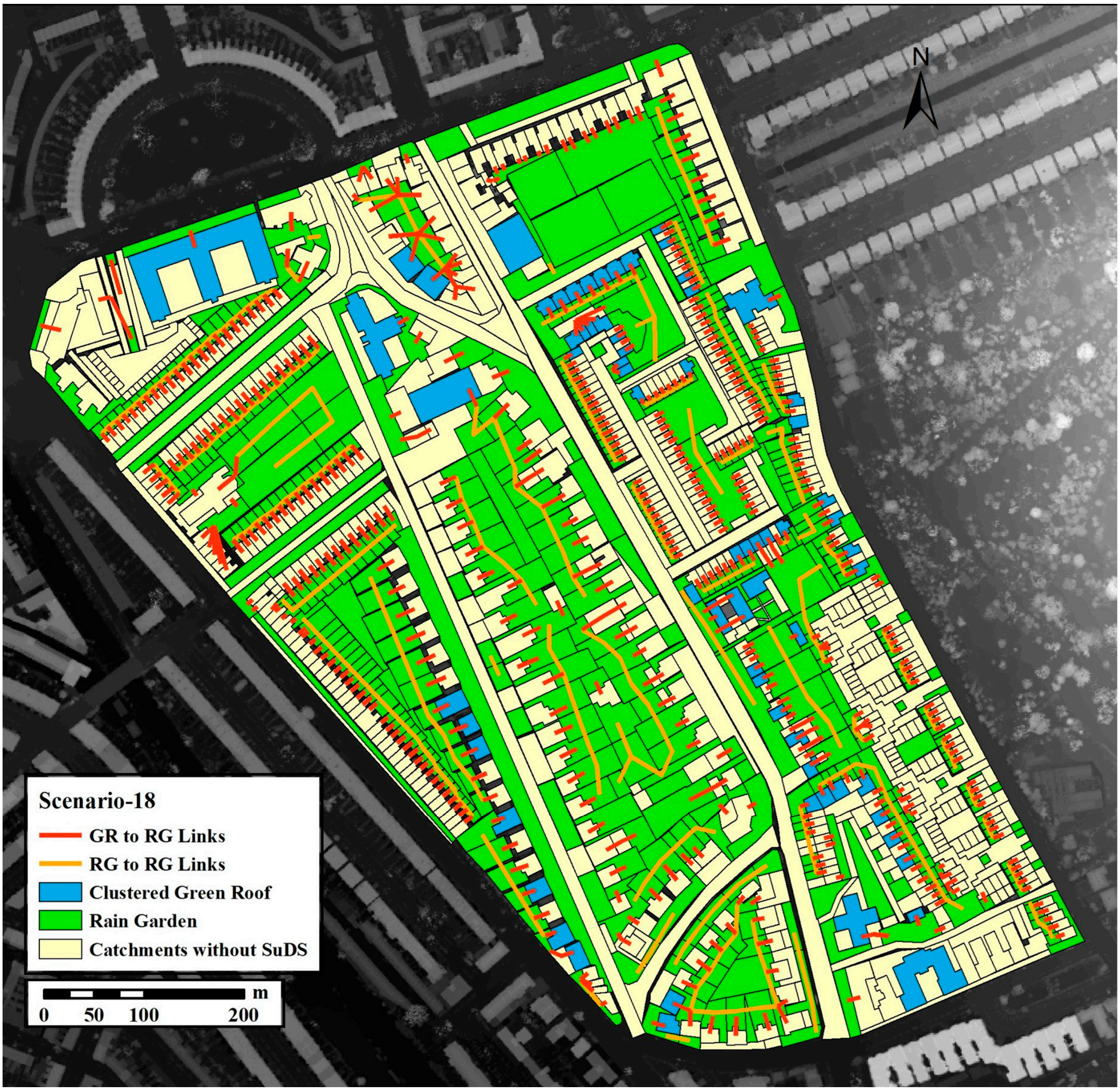

Fig. S19. The sketch map of Scenario 18

Scenario 18: No rain garden in each subcatchment is clustered, and 622 green roofs are clustered in 69 bigger mini-catchments of buildings; the runoff from 526 building roofs is drained to nearby green land; the water in 422 of the adjacent green land flows in one direction to the next in turn.

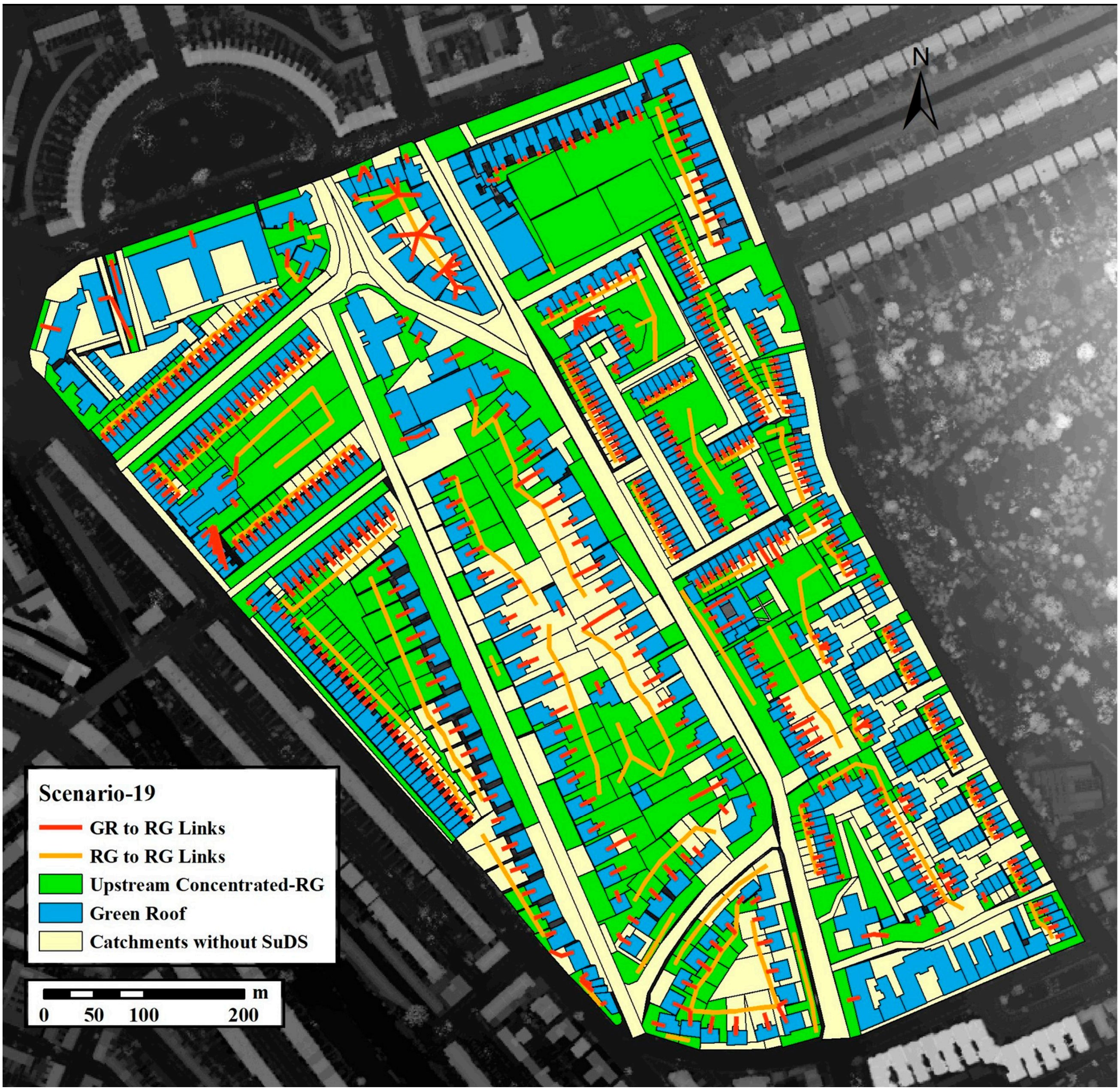

Fig. S20. The sketch map of Scenario 19

Scenario 19: One green roof unit is applied to each mini-catchment of buildings; runoff from 526 green roofs is drained to nearby rain gardens; the water in 233 of the adjacent rainwater gardens flows in one direction to the next in turn; one rain garden unit is applied on each upstream mini-catchment of adjacent green land; no clustered SuDS component exists.

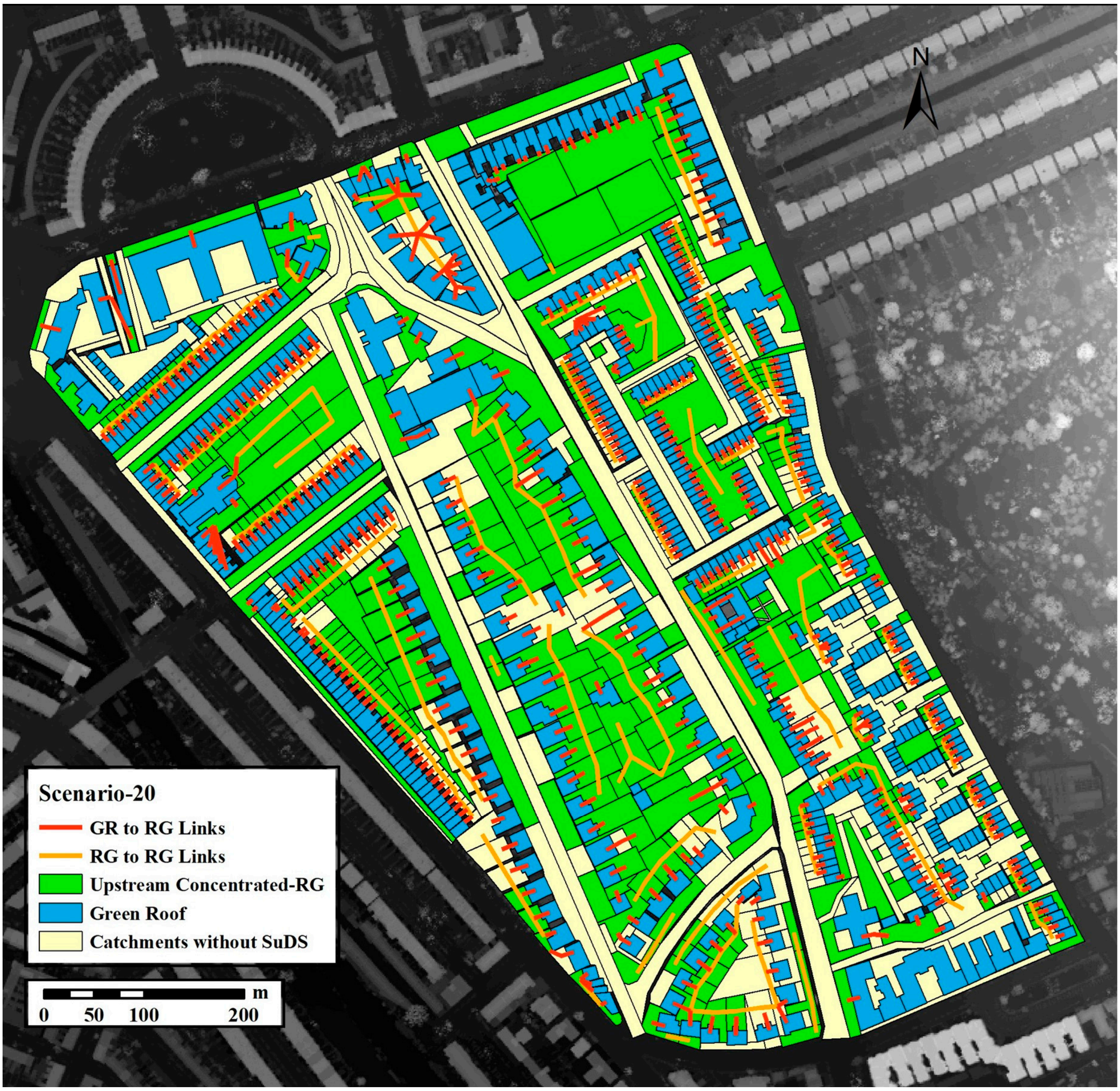

Fig. S21. The sketch map of Scenario 20

Scenario 20: One green roof unit is applied to each mini-catchment of buildings; runoff from 526 green roofs is drained to nearby rain gardens; the water in 233 of the adjacent rainwater gardens flows in one direction to the next in turn; one rain garden unit is applied on each upstream mini-catchment of adjacent green land; no clustered SuDS component exists.

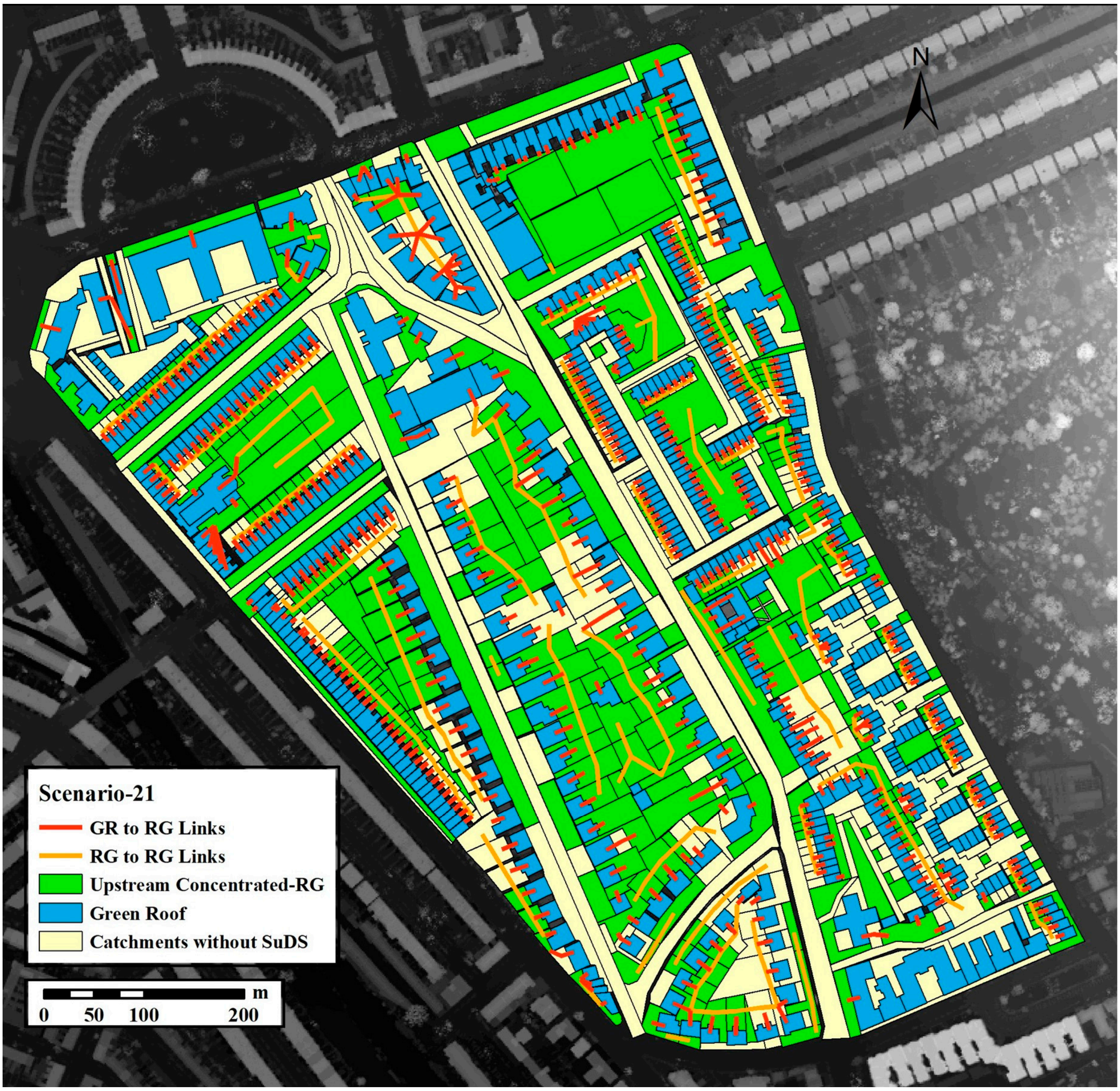

Fig. S22. The sketch map of Scenario 21

Scenario 21: One green roof unit is applied to each mini-catchment of buildings; runoff from 526 green roofs is drained to nearby rain gardens; the water in 233 of the adjacent rainwater gardens flows in one direction to the next in turn; one rain garden unit is applied on each upstream mini-catchment of adjacent green land; no clustered SuDS component exists.

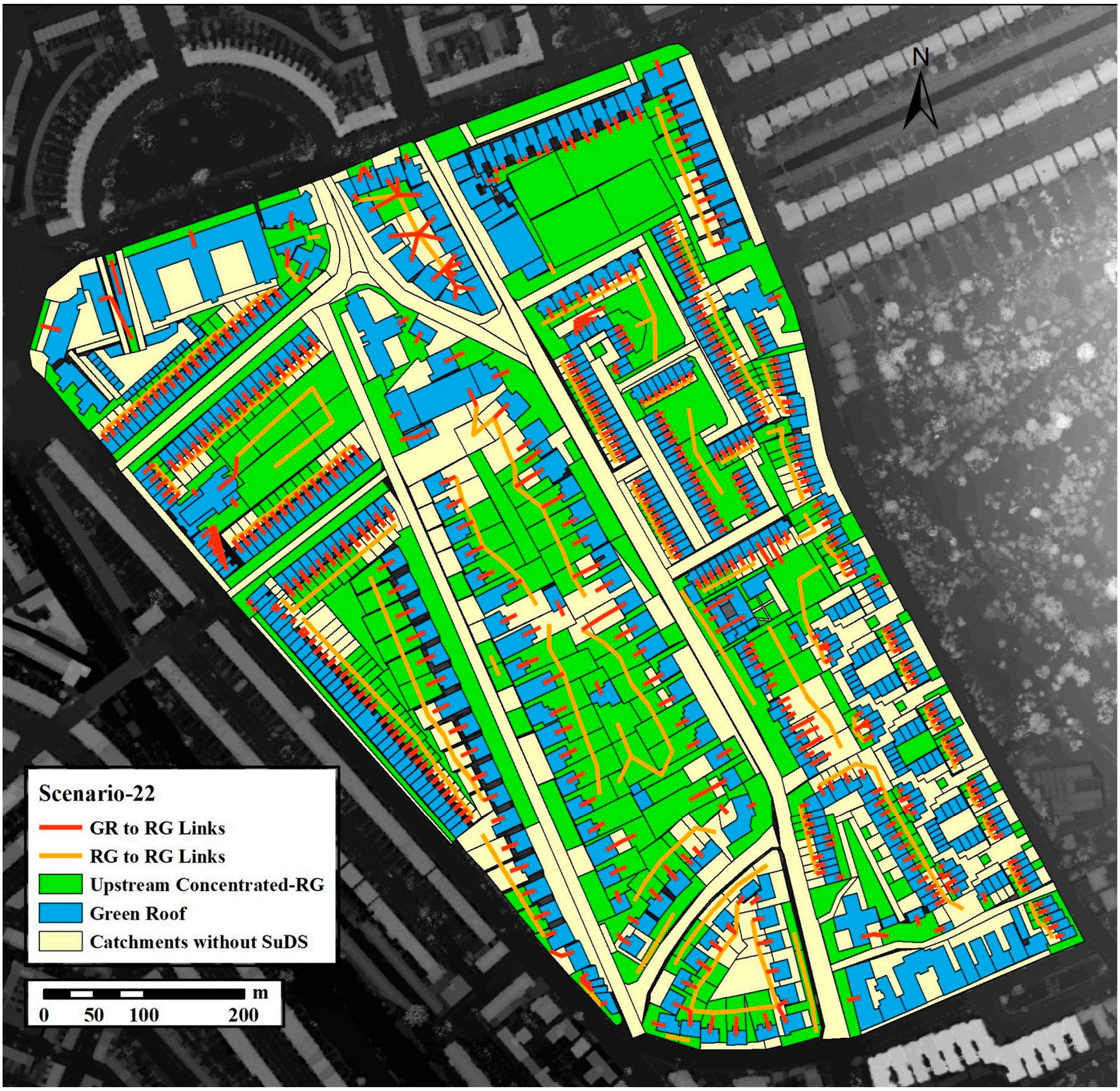

Fig. S23. The sketch map of Scenario 22

Scenario 22: One green roof unit is applied to each mini-catchment of buildings; runoff from 526 green roofs is drained to nearby rain gardens; the water in 233 of the adjacent rainwater gardens flows in one direction to the next in turn; one rain garden unit is applied on each upstream mini-catchment of adjacent green land; no clustered SuDS component exists.

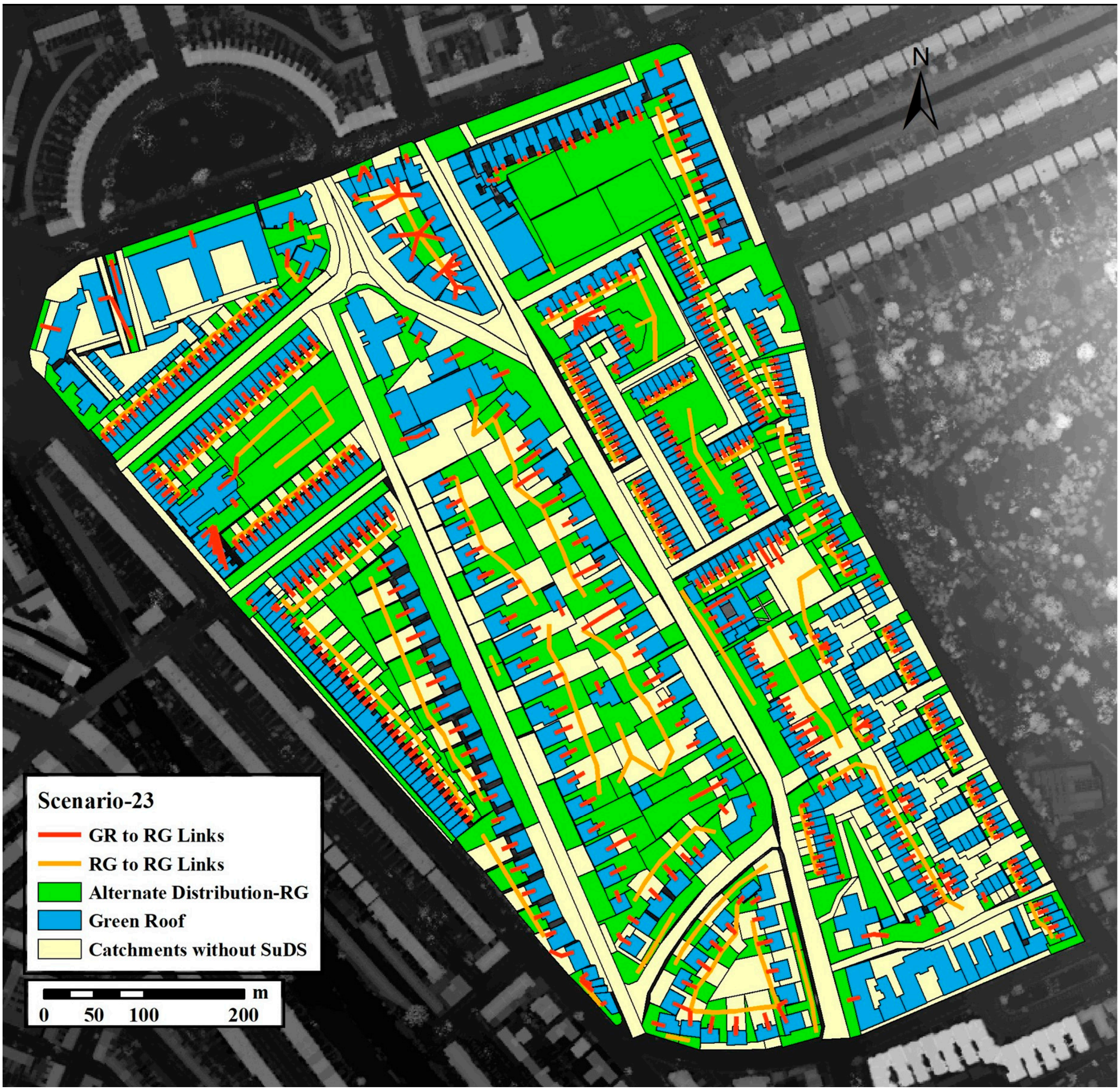

Fig. S24. The sketch map of Scenario 23

Scenario 23: One green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; the water in 233 of the adjacent rainwater gardens flows in one direction to the next in turn; one rain garden unit is applied on each even-numbered mini-catchment of adjacent green land; no clustered SuDS component exists.

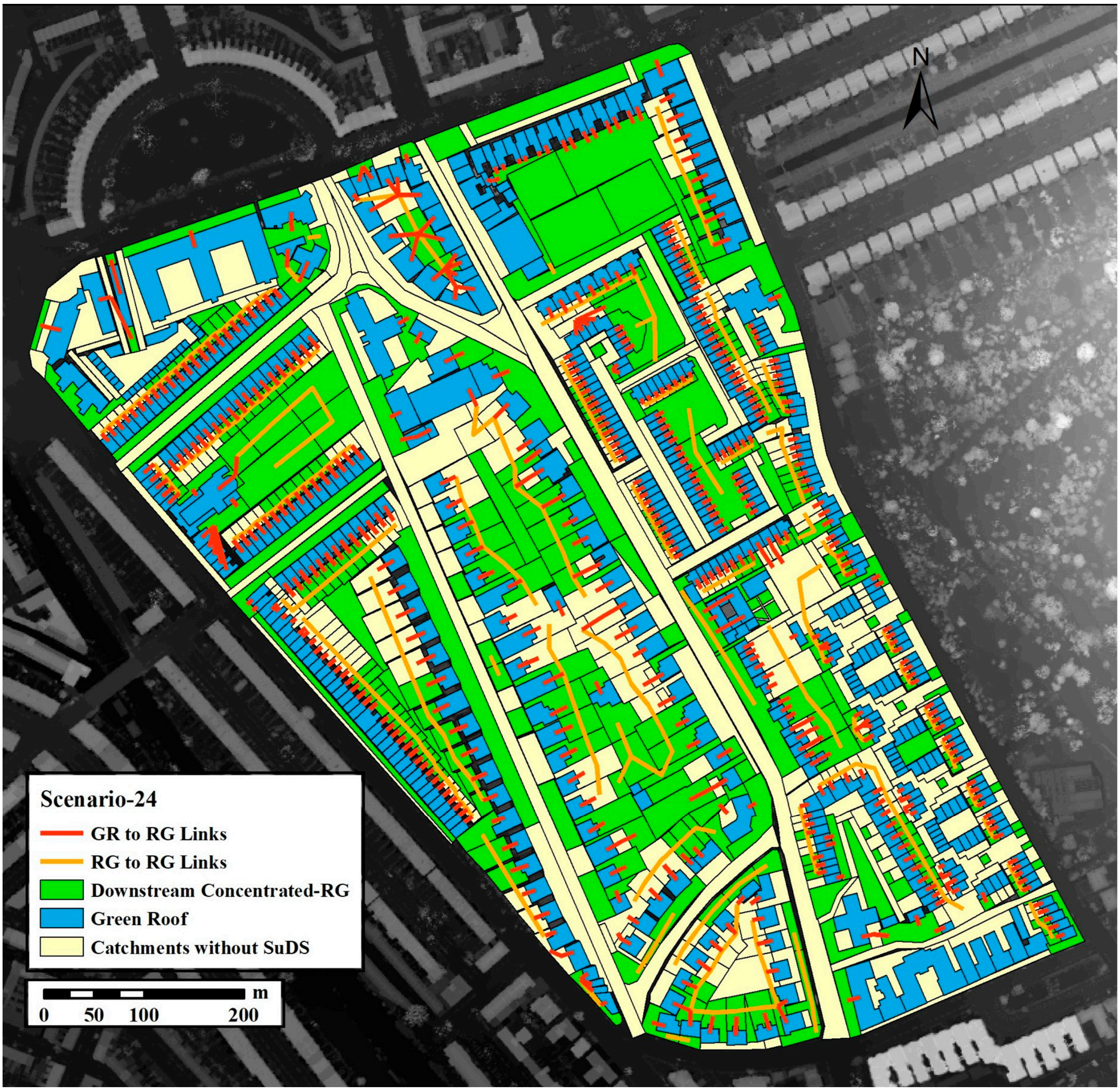

Fig. S25. The sketch map of Scenario 24

Scenario 24: One green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; the water in 233 of the adjacent rainwater gardens flows in one direction to the next in turn; one rain garden unit is applied on each downstream mini-catchment of adjacent green land; no clustered SuDS component exists.

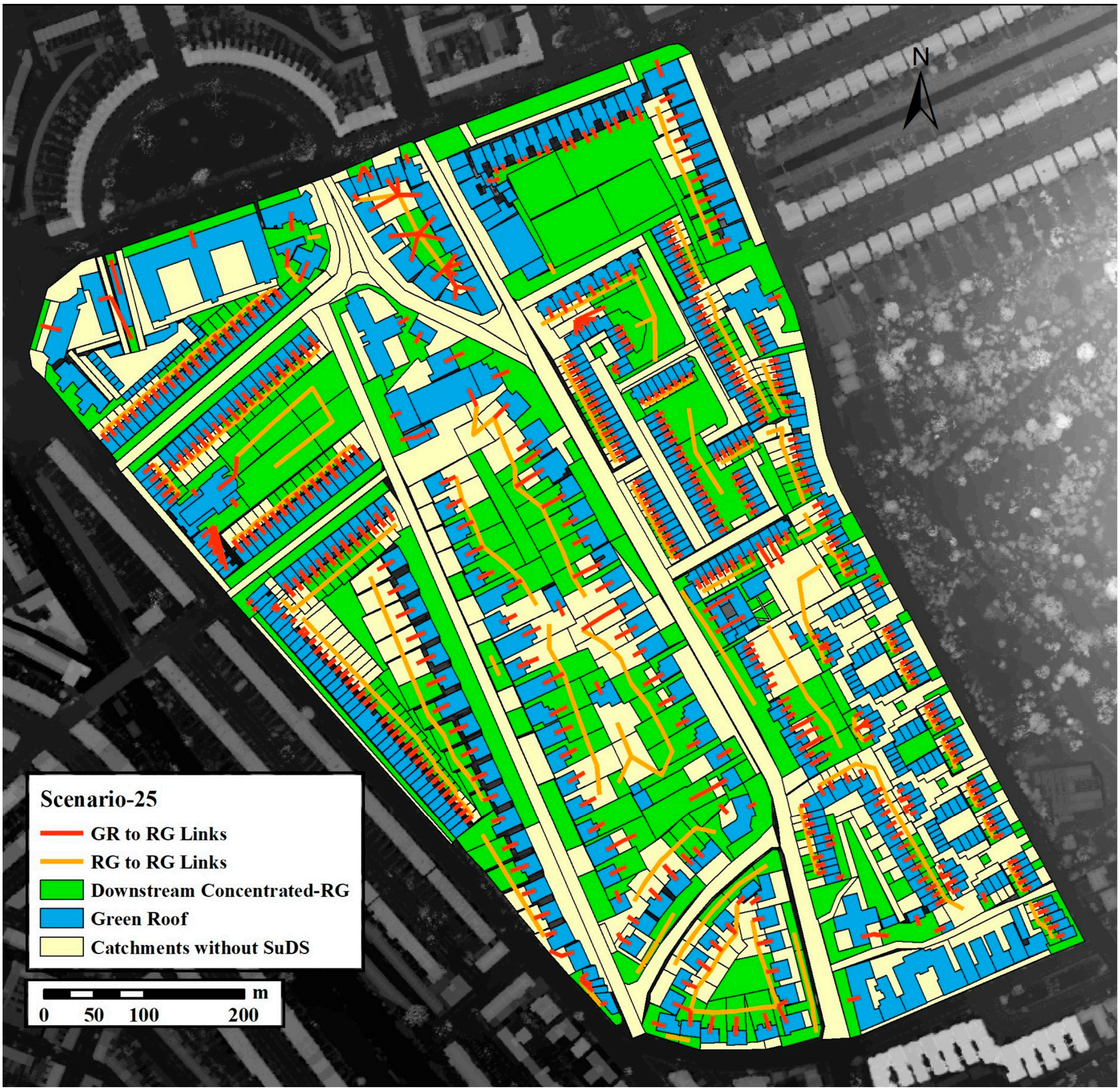

Fig. S26. The sketch map of Scenario 25

Scenario 25: One green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; the water in 233 of the adjacent rainwater gardens flows in one direction to the next in turn; one rain garden unit is applied on each downstream mini-catchment of adjacent green land; no clustered SuDS component exists.

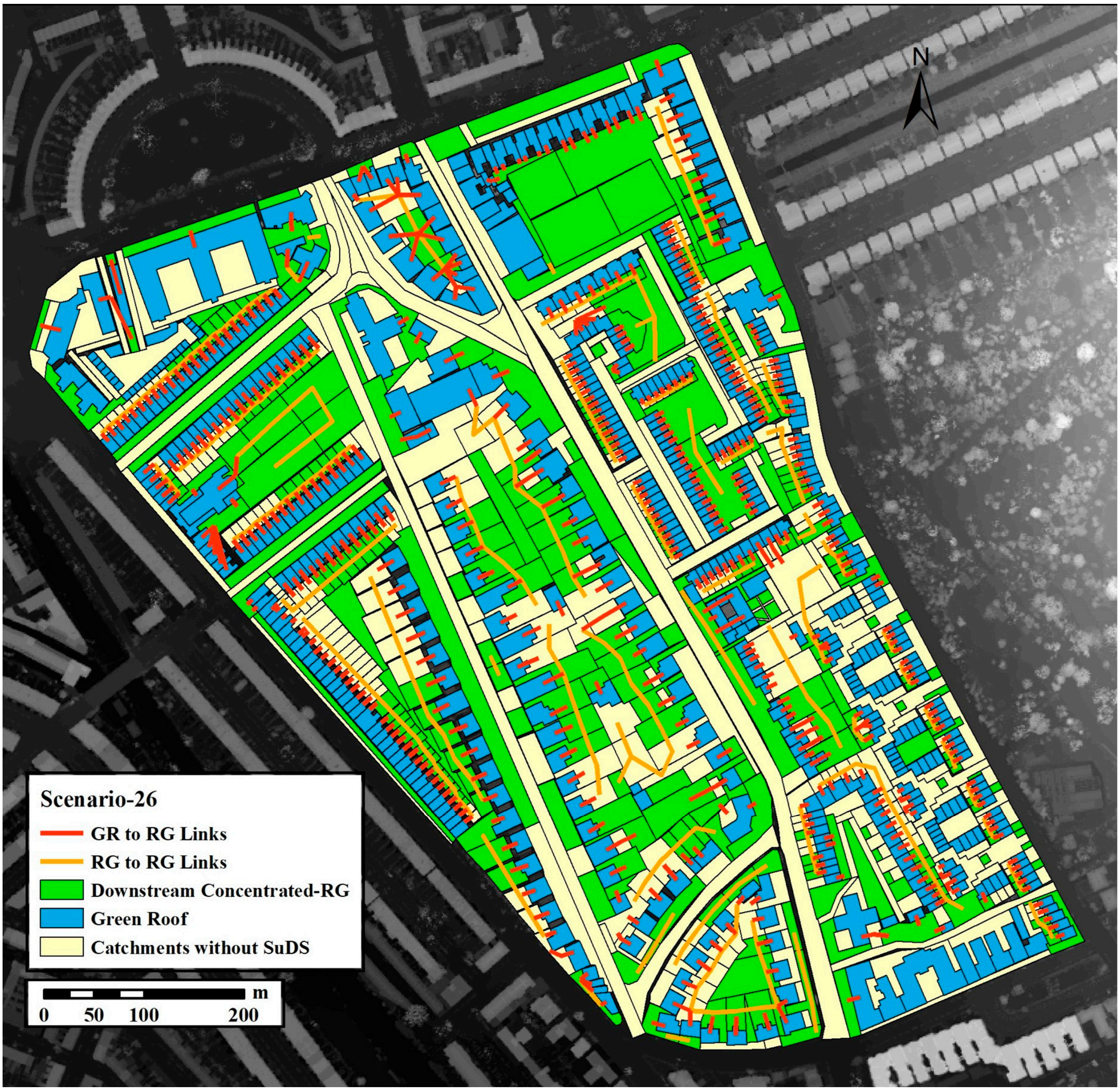

Fig. S27. The sketch map of Scenario 26

Scenario 26: One green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; the water in 233 of the adjacent rainwater gardens flows in one direction to the next in turn; one rain garden unit is applied on each downstream mini-catchment of adjacent green land; no clustered SuDS component exists.

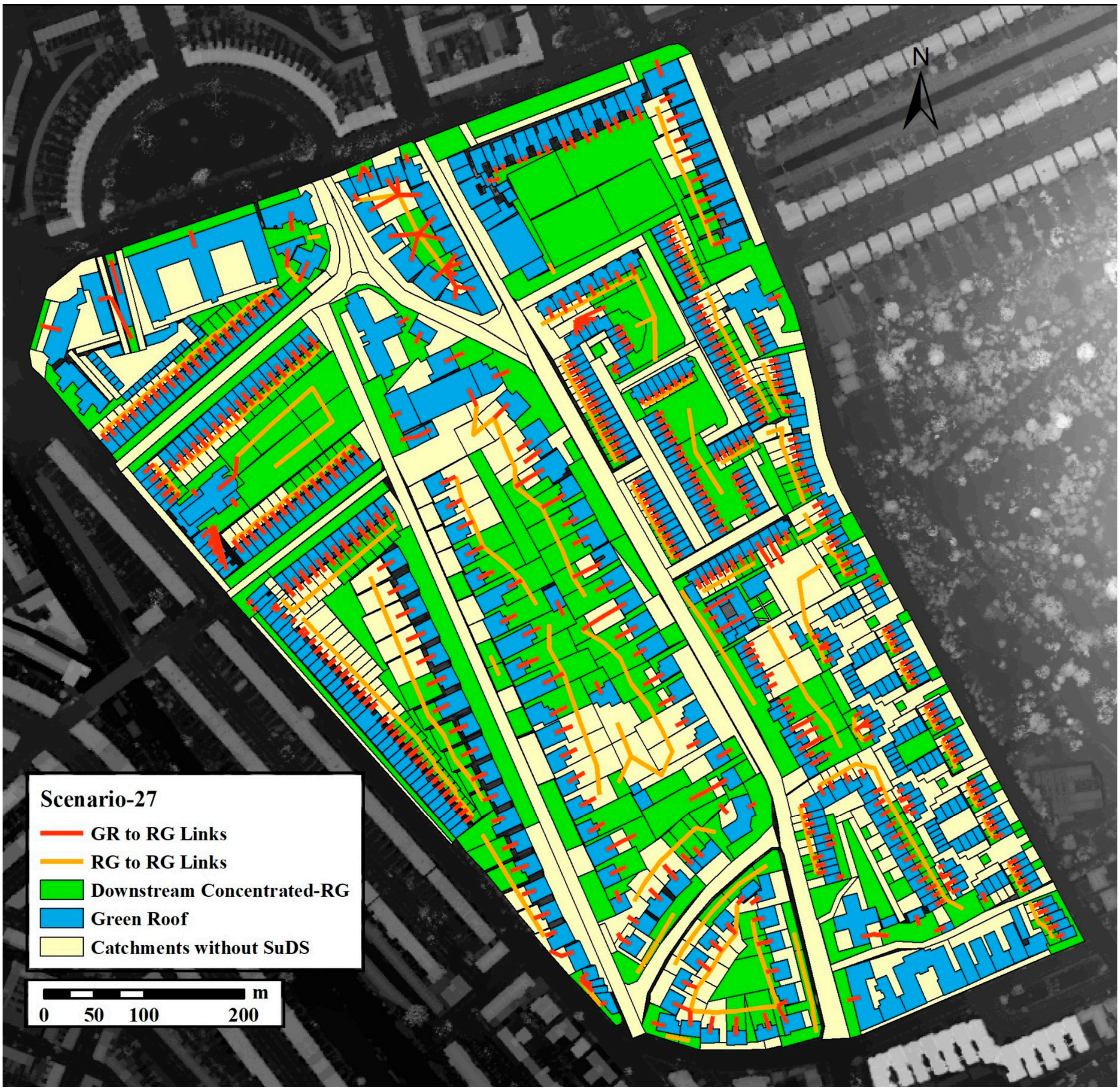

Fig. S28. The sketch map of Scenario 27

Scenario 27: One green roof unit is applied to each mini-catchment of buildings; the runoff from 526 green roofs is drained to nearby rain gardens; the water in 233 of the adjacent rainwater gardens flows in one direction to the next in turn; one rain garden unit is applied on each downstream mini-catchment of adjacent green land; no clustered SuDS component exists.

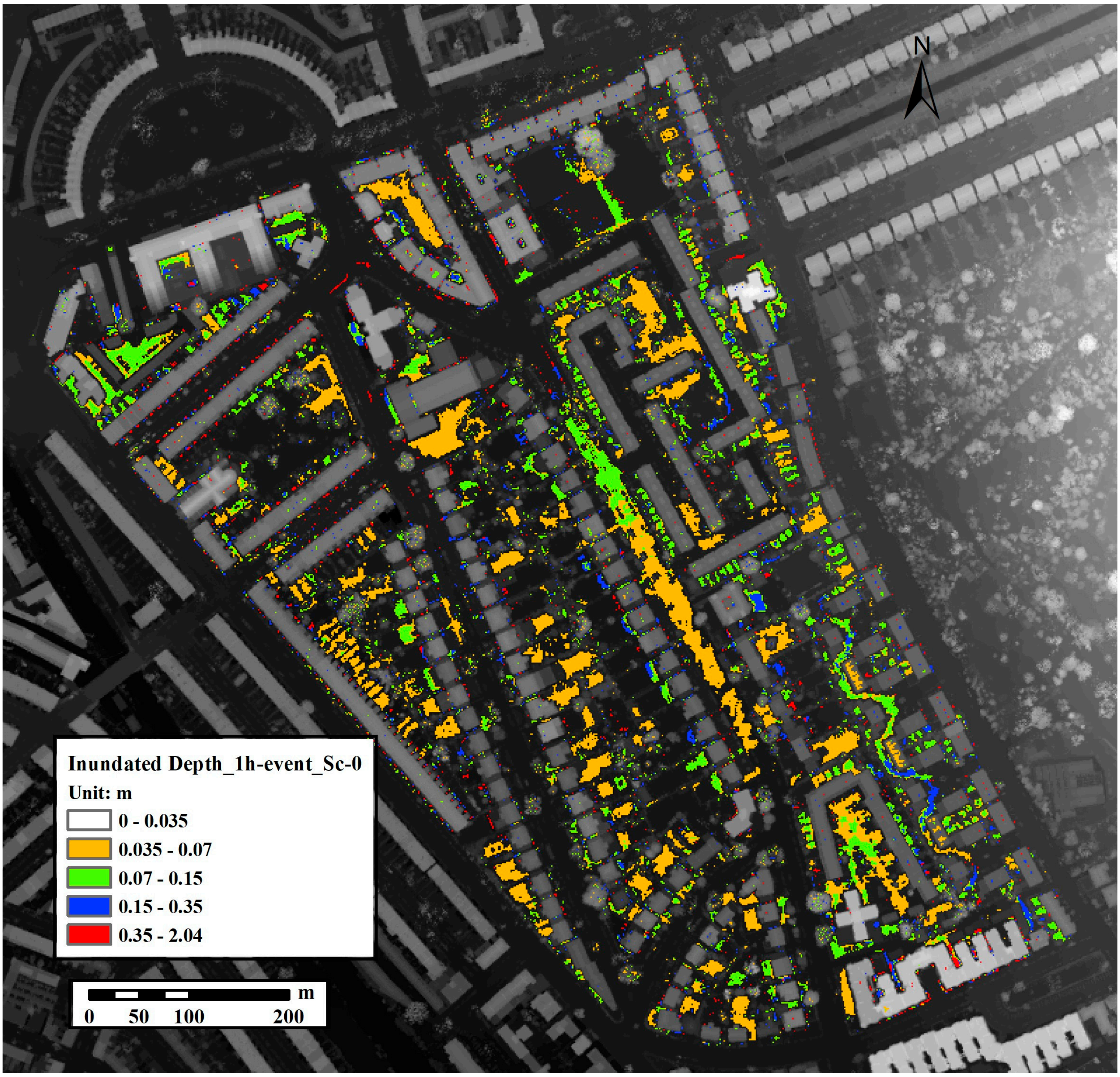

Fig. S29. Flood map of scenario 0 at the time of 2h (1-hour rainfall event)

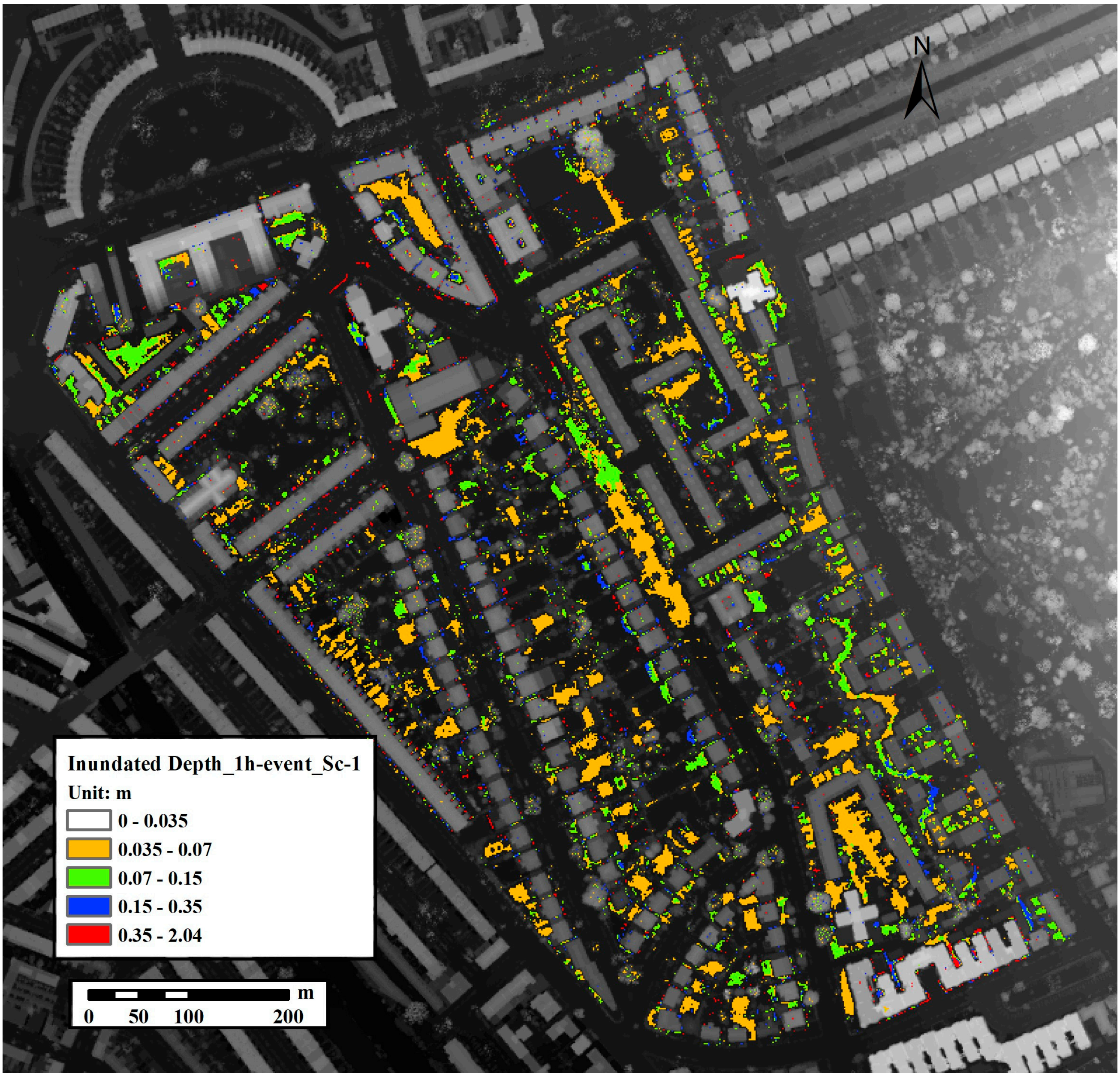

Fig. S30. Flood map of scenario 1 at the time of 2h (1-hour rainfall event)

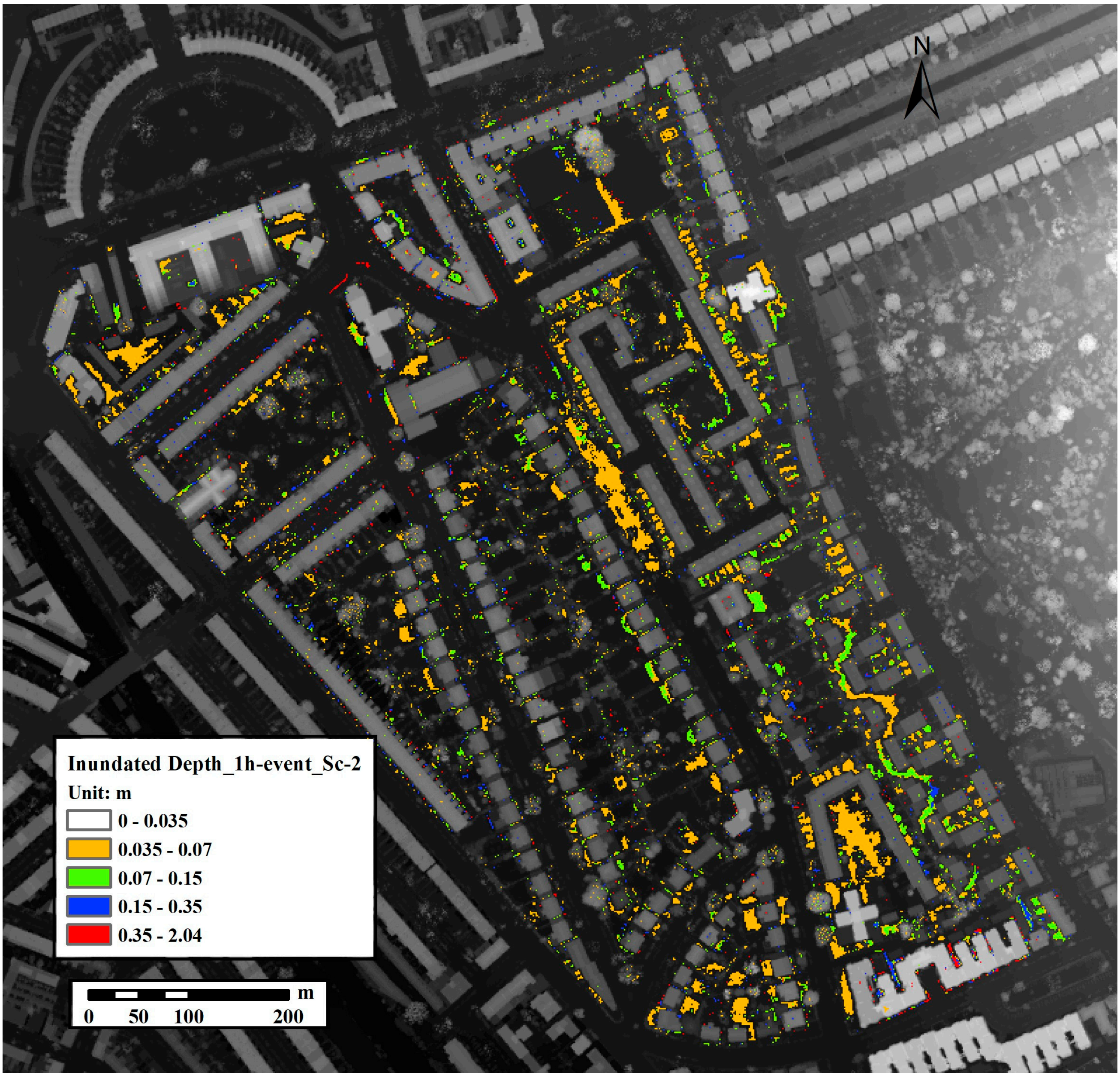

Fig. S31. Flood map of scenario 2 at the time of 2h (1-hour rainfall event)

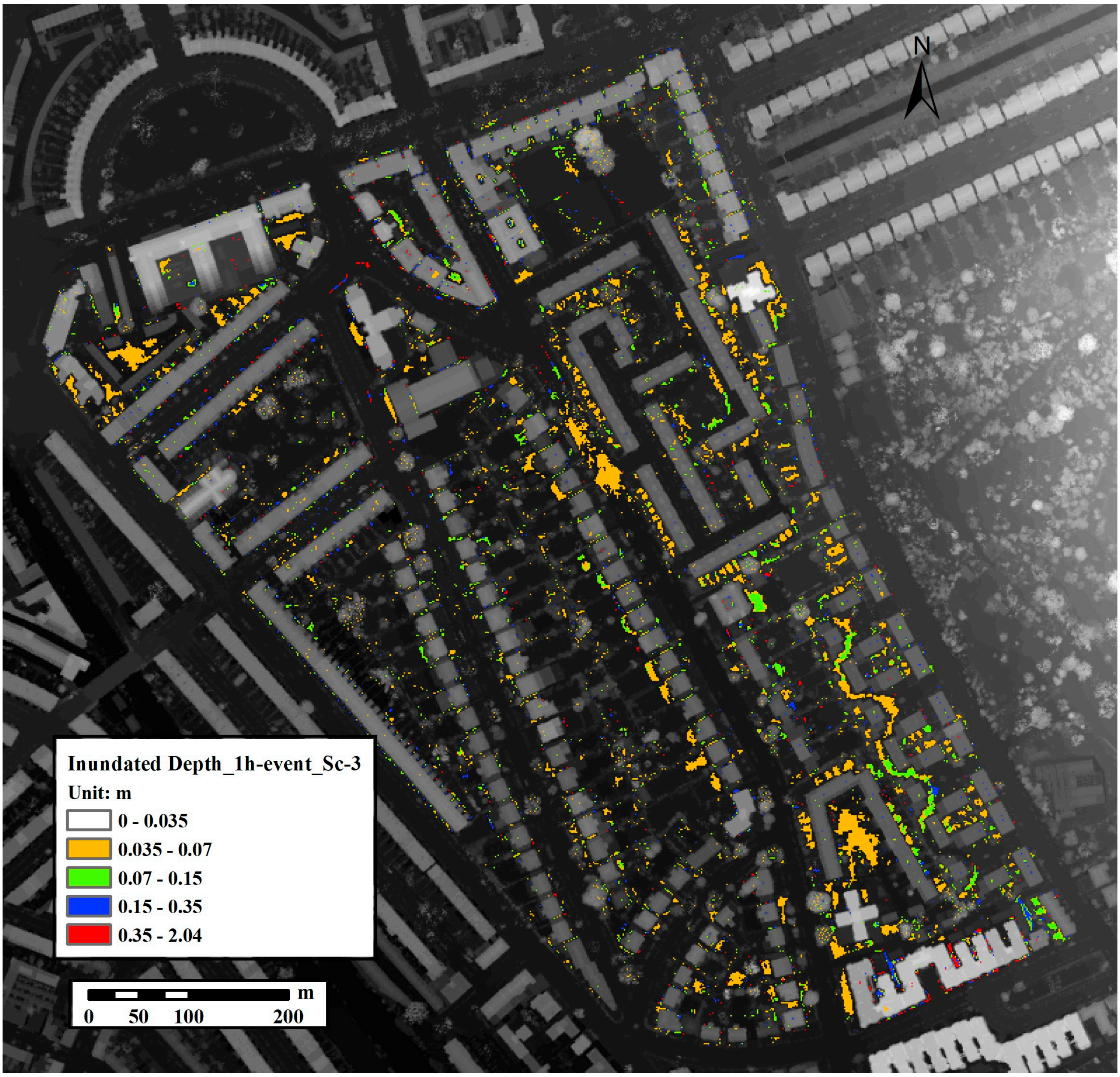

Fig. S32. Flood map of scenario 3 at the time of 2h (1-hour rainfall event)

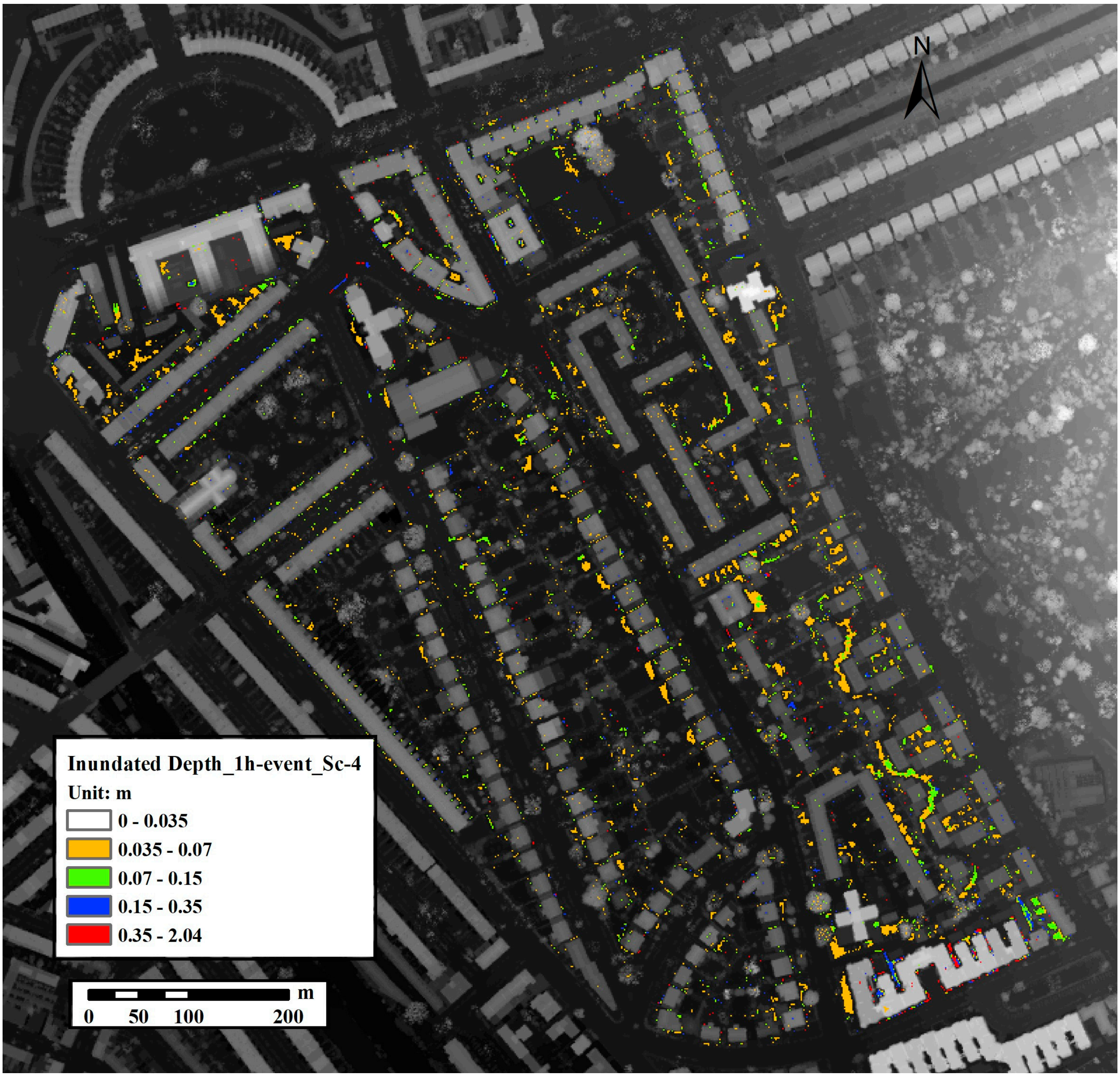

Fig. S33. Flood map of scenario 4 at the time of 2h (1-hour rainfall event)

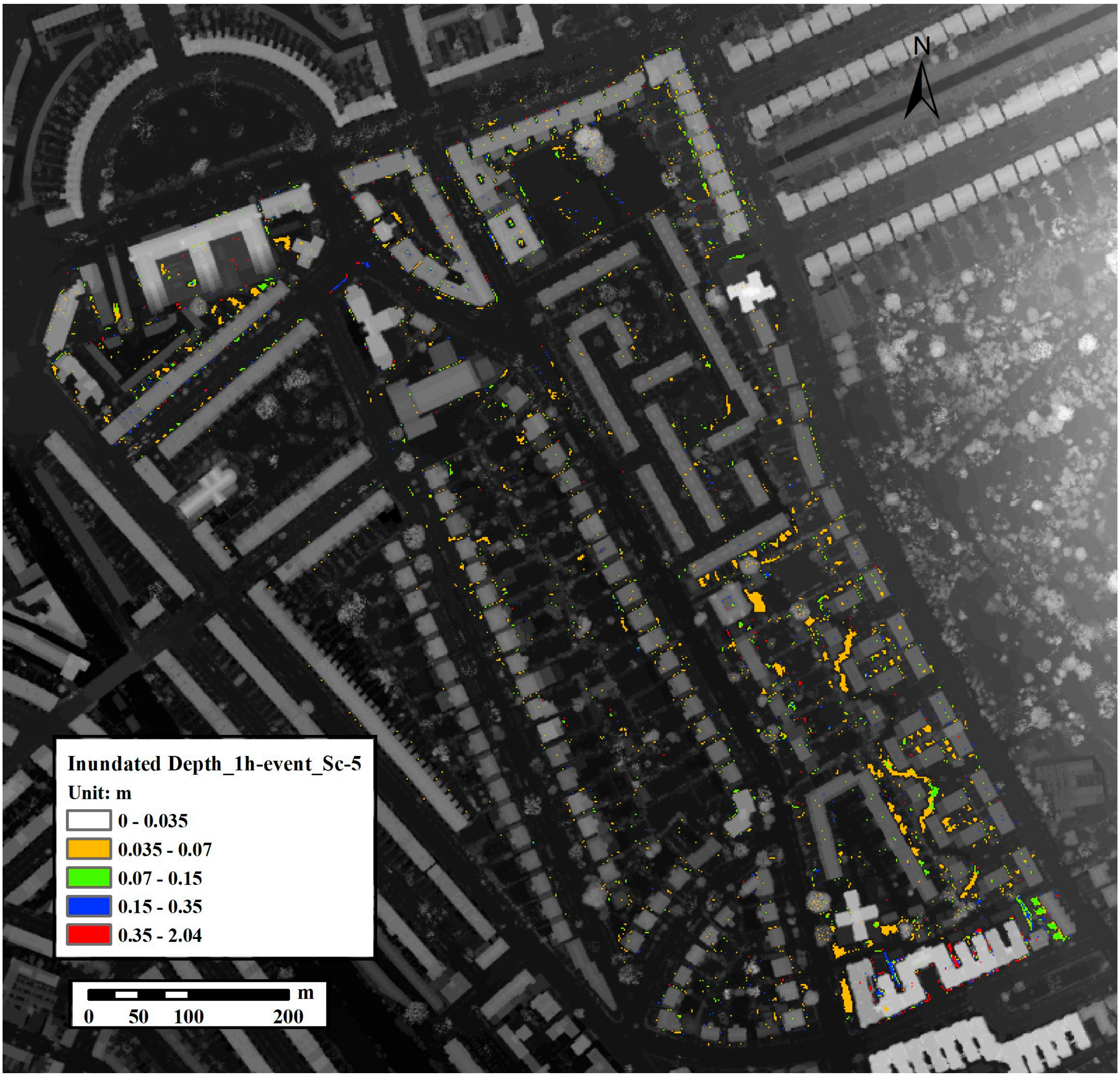

Fig. S34. Flood map of scenario 5 at the time of 2h (1-hour rainfall event)

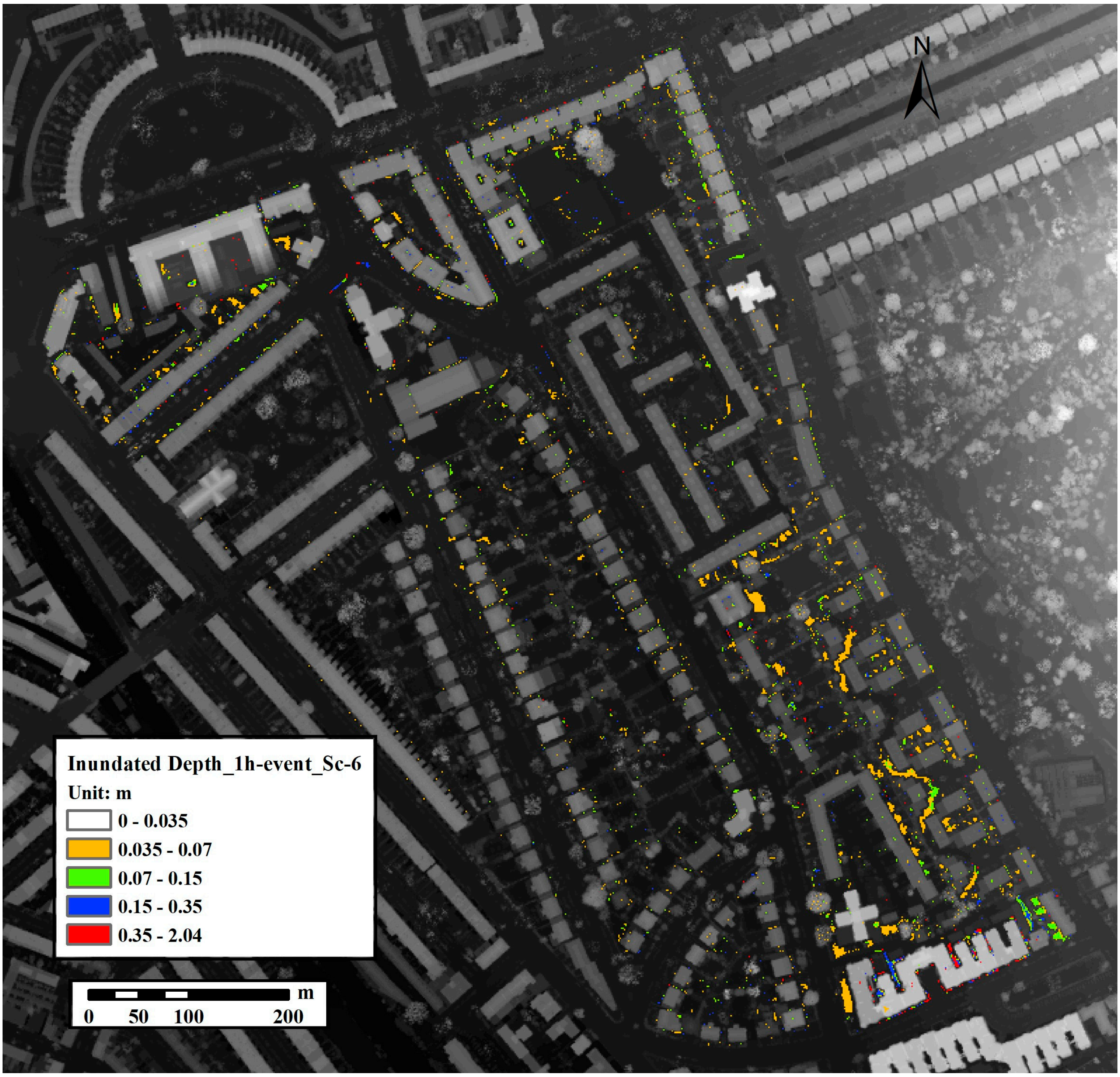

Fig. S35. Flood map of scenario 6 at the time of 2h (1-hour rainfall event)

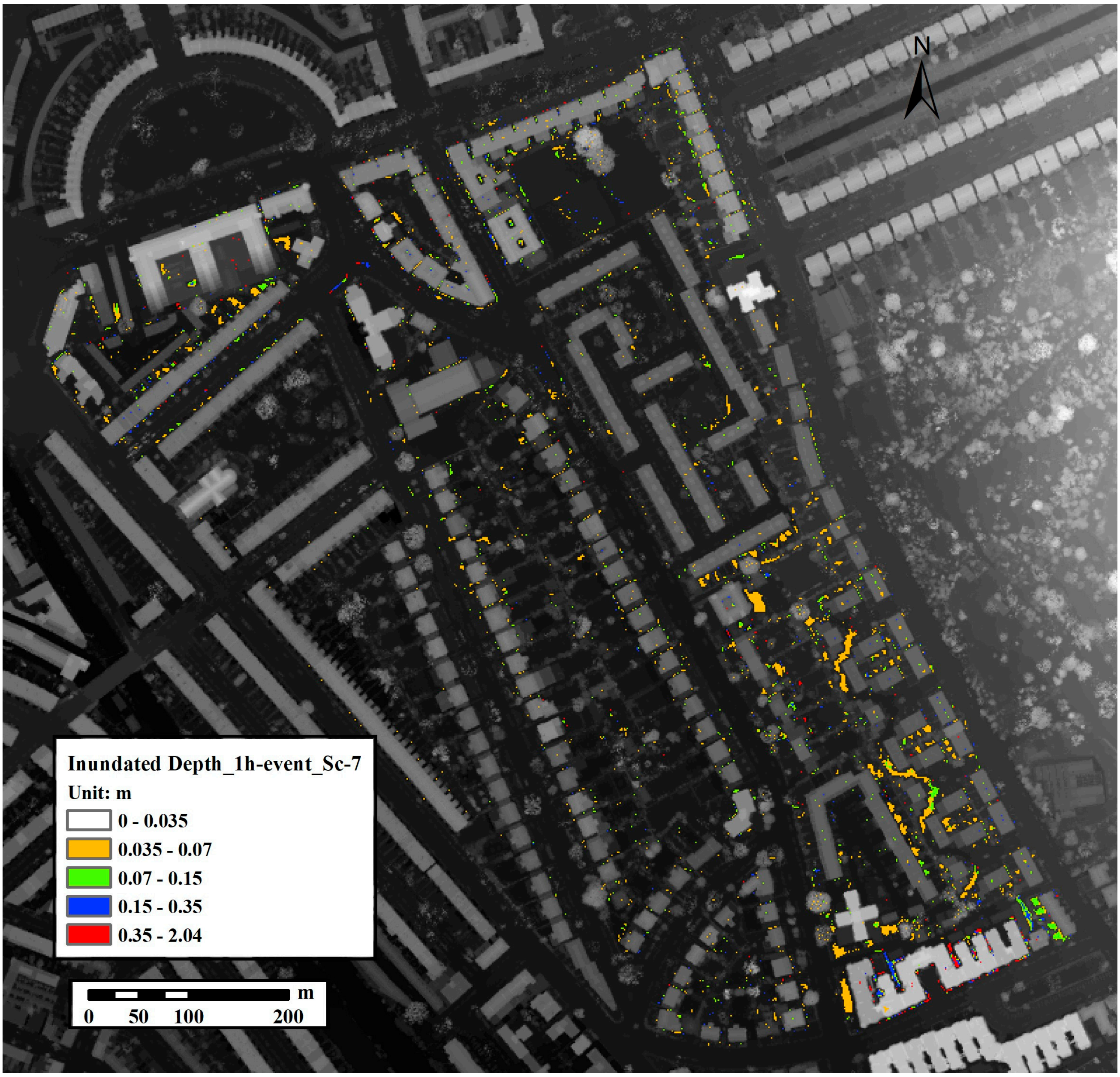

Fig. S36. Flood map of scenario 7 at the time of 2h (1-hour rainfall event)

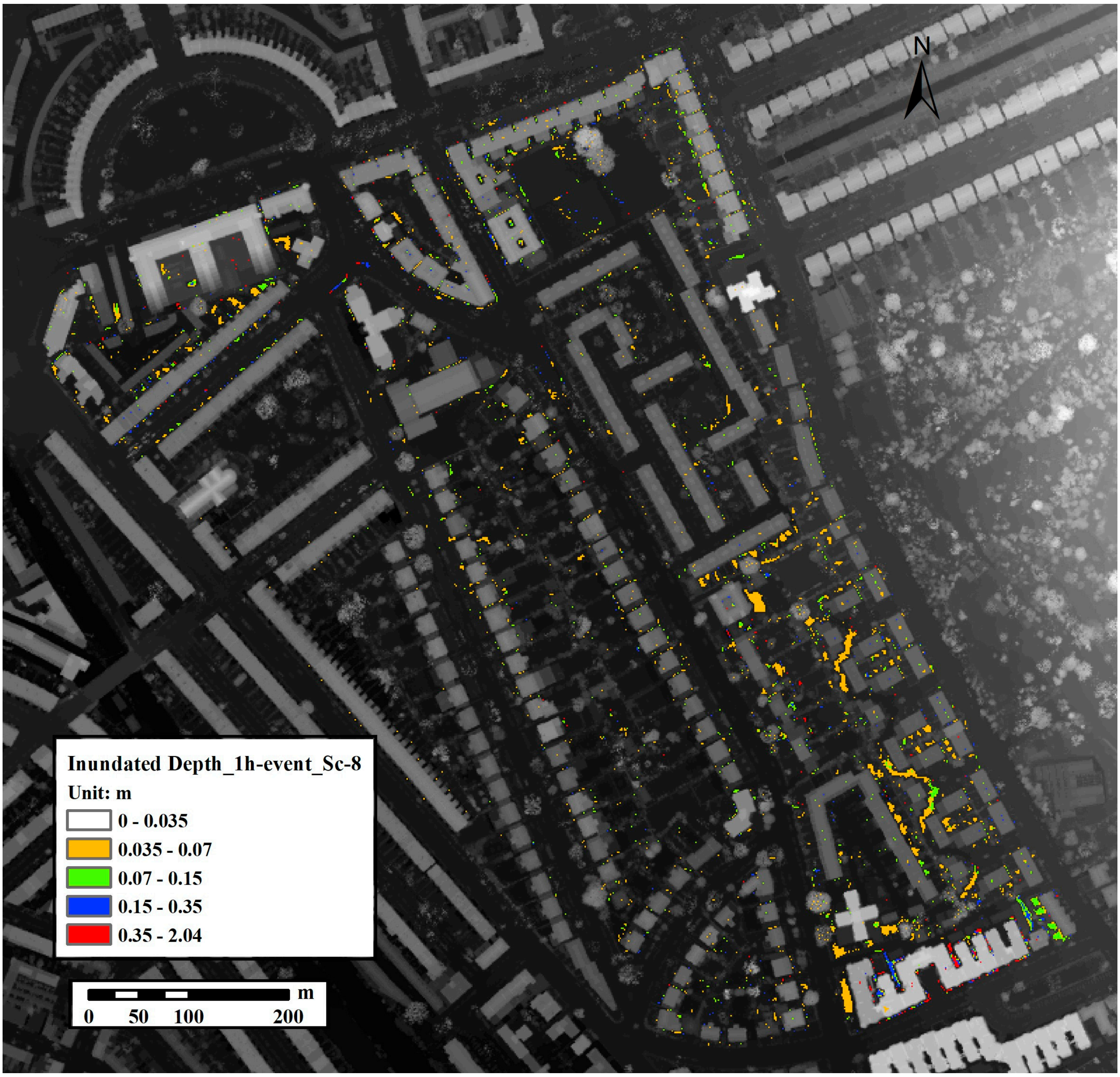

Fig. S37. Flood map of scenario 8 at the time of 2h (1-hour rainfall event)

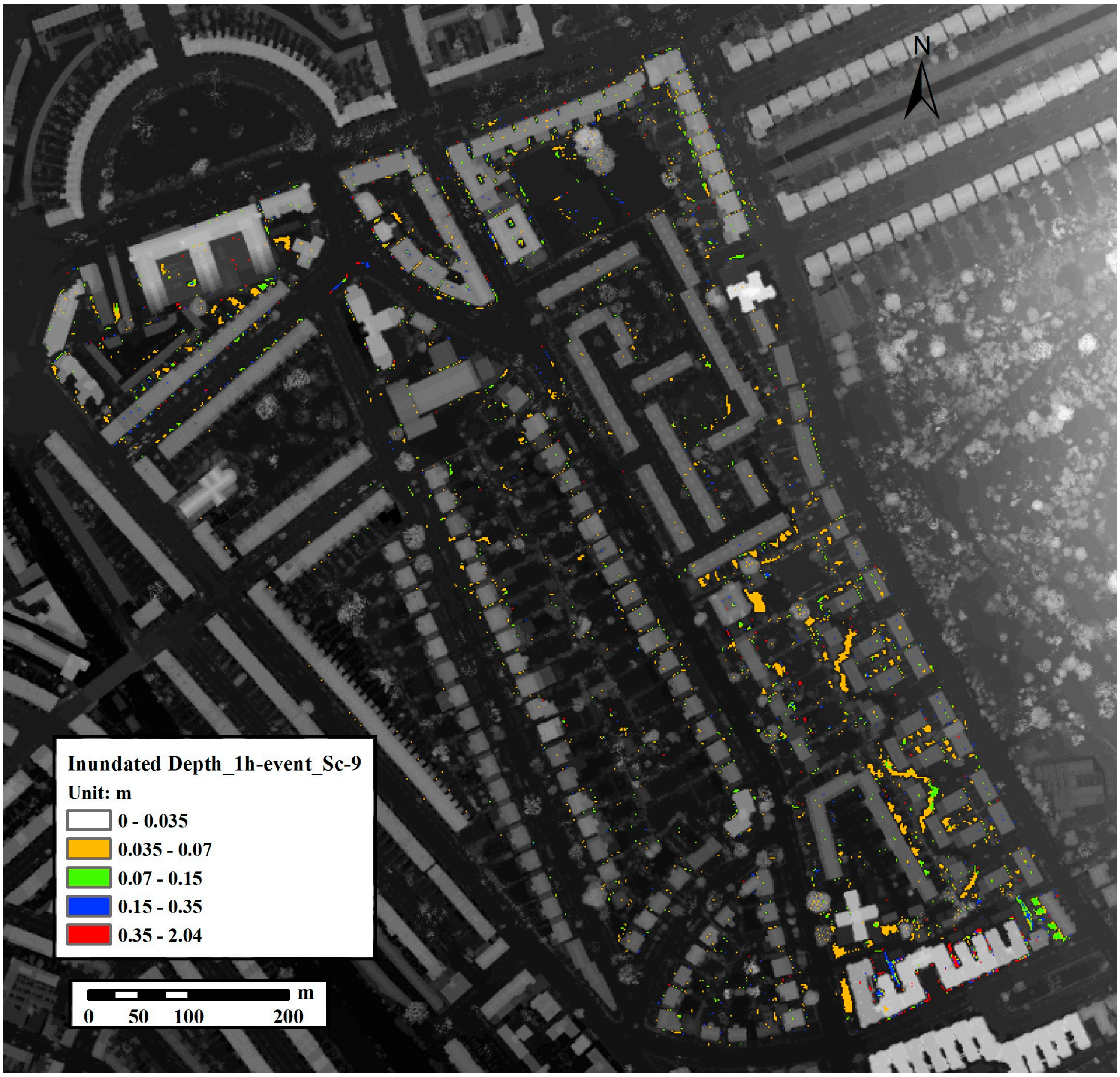

Fig. S38. Flood map of scenario 9 at the time of 2h (1-hour rainfall event)

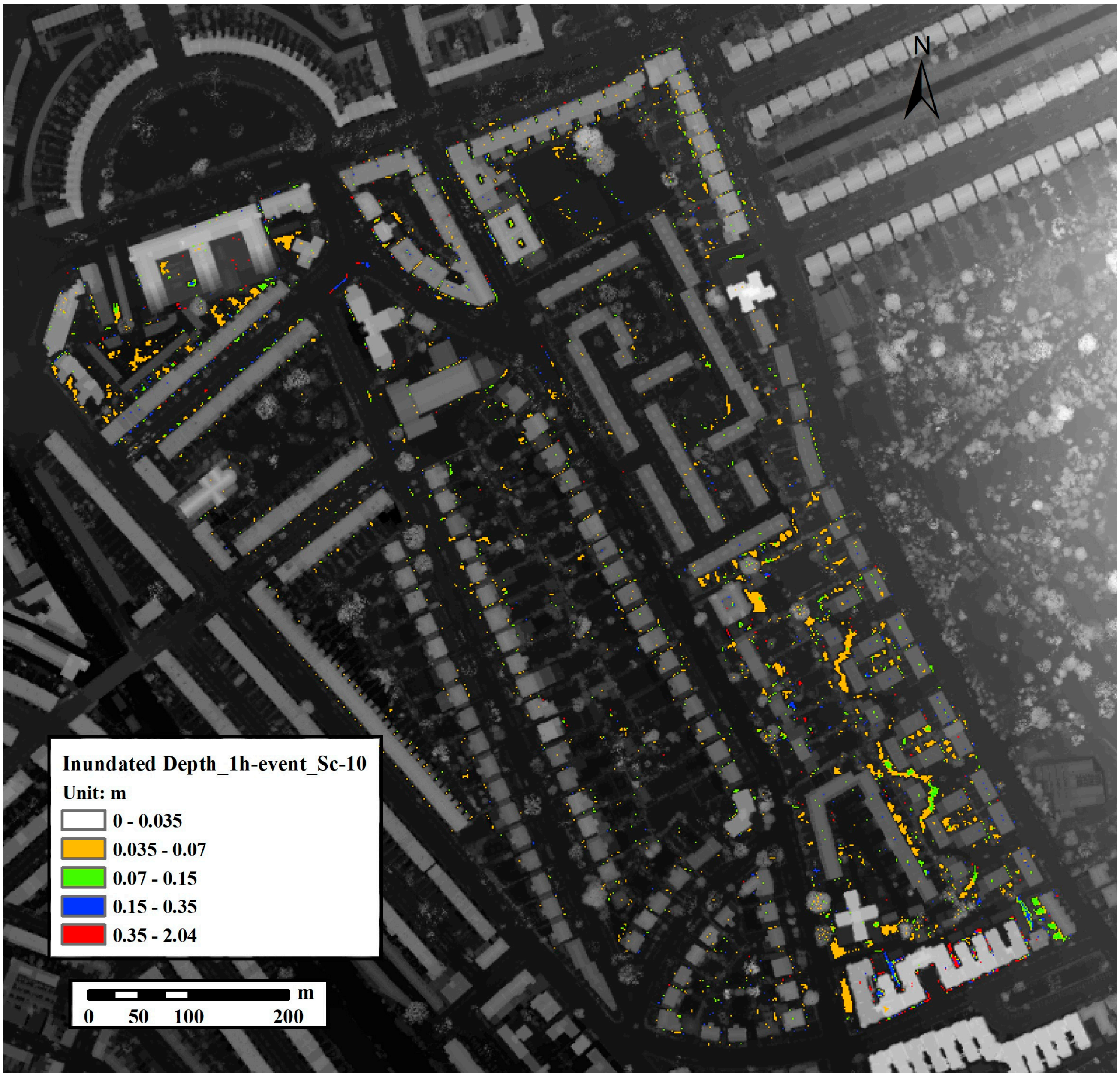

Fig. S39. Flood map of scenario 10 at the time of 2h (1-hour rainfall event)

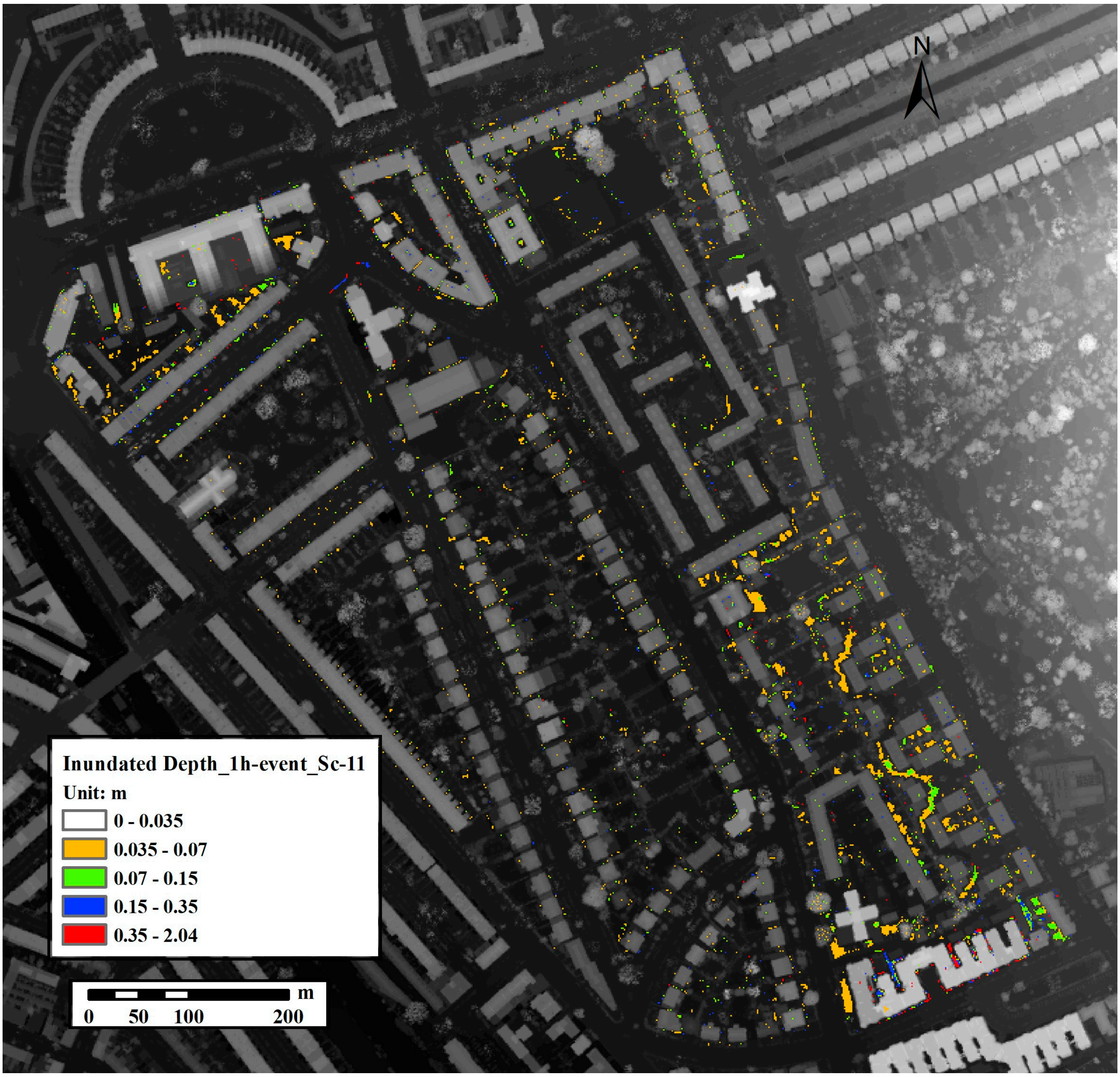

Fig. S40. Flood map of scenario 11 at the time of 2h (1-hour rainfall event)

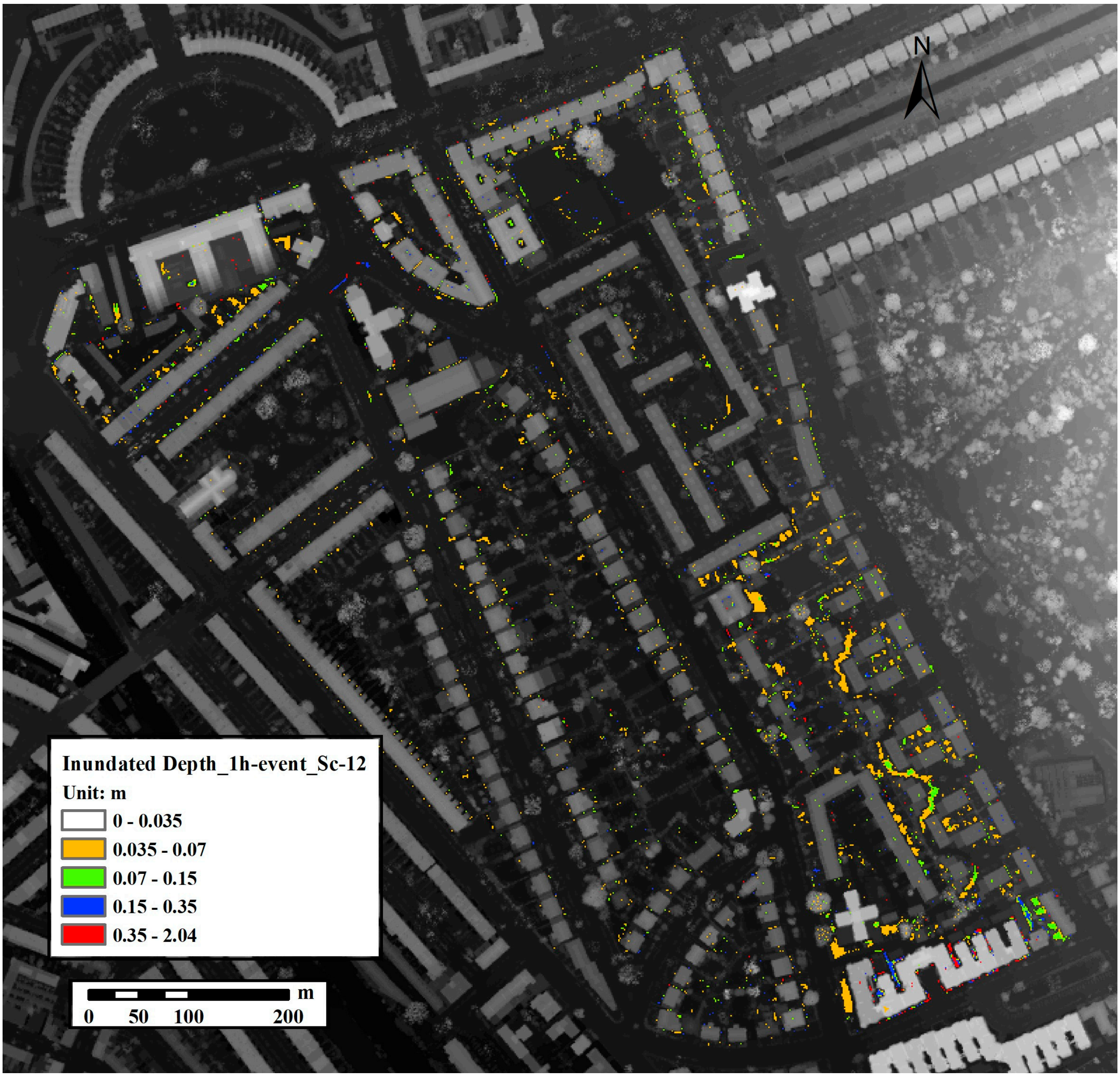

Fig. S41. Flood map of scenario 12 at the time of 2h (1-hour rainfall event)

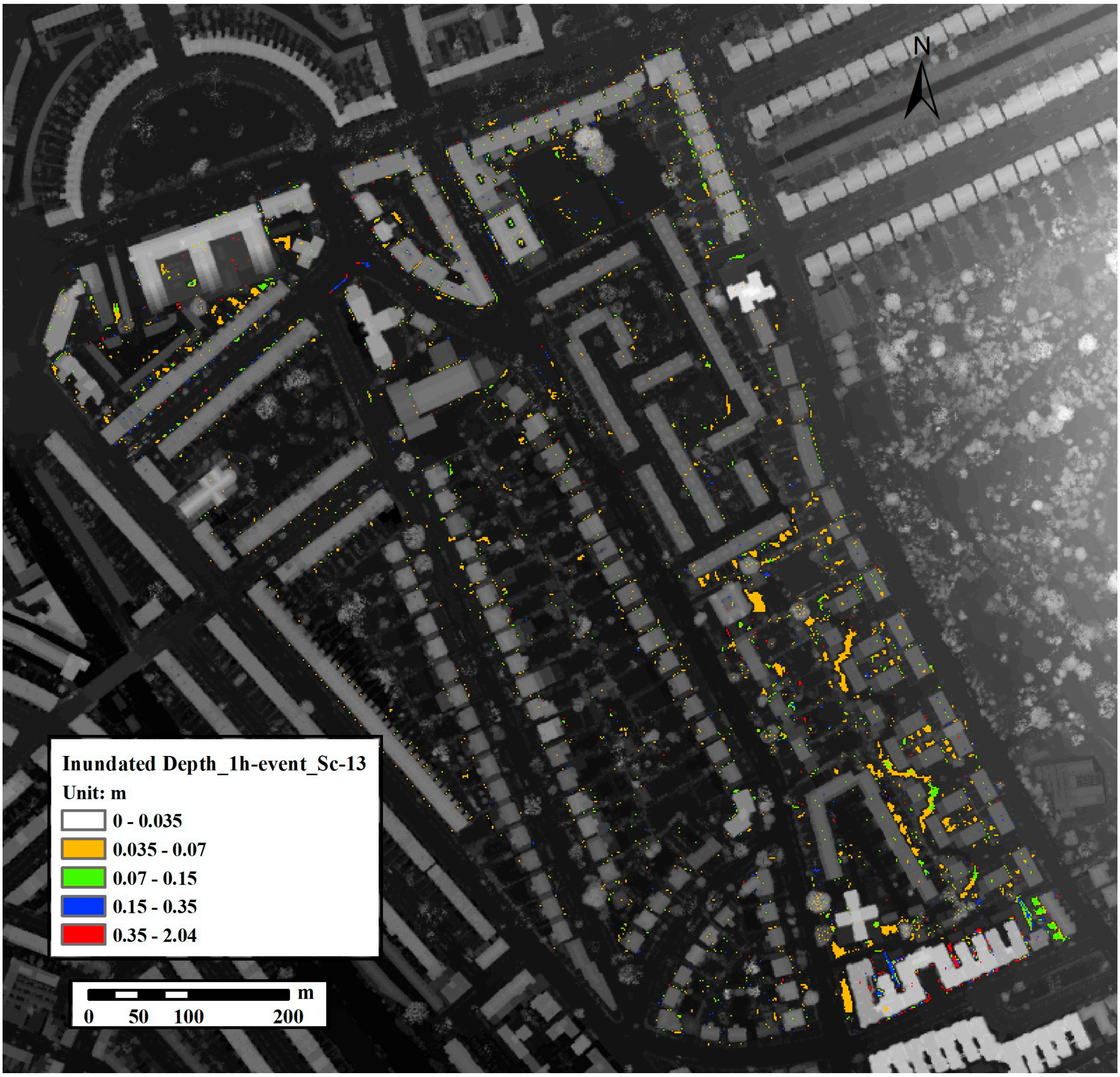

Fig. S42. Flood map of scenario 13 at the time of 2h (1-hour rainfall event)

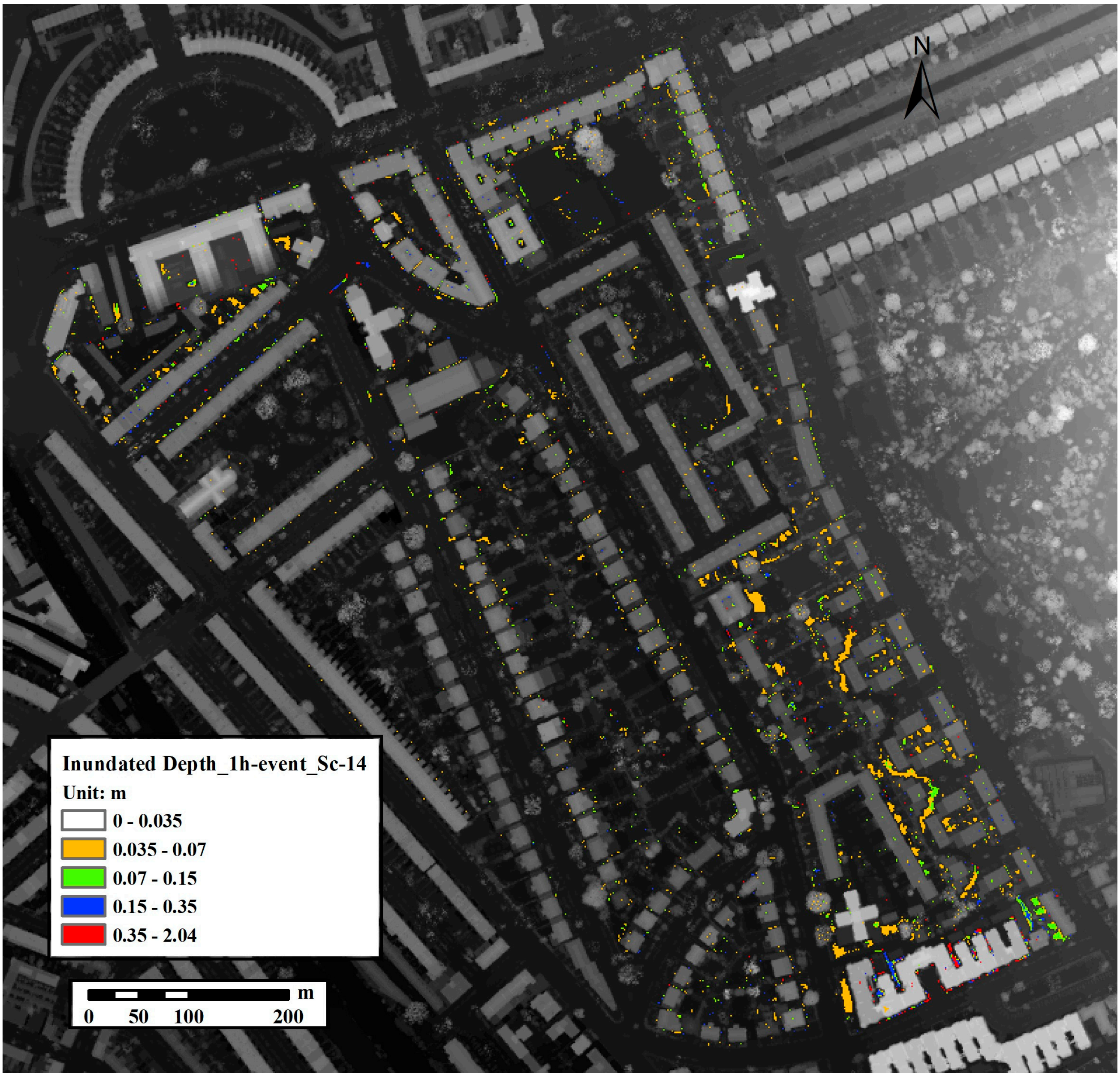

Fig. S43. Flood map of scenario 14 at the time of 2h (1-hour rainfall event)

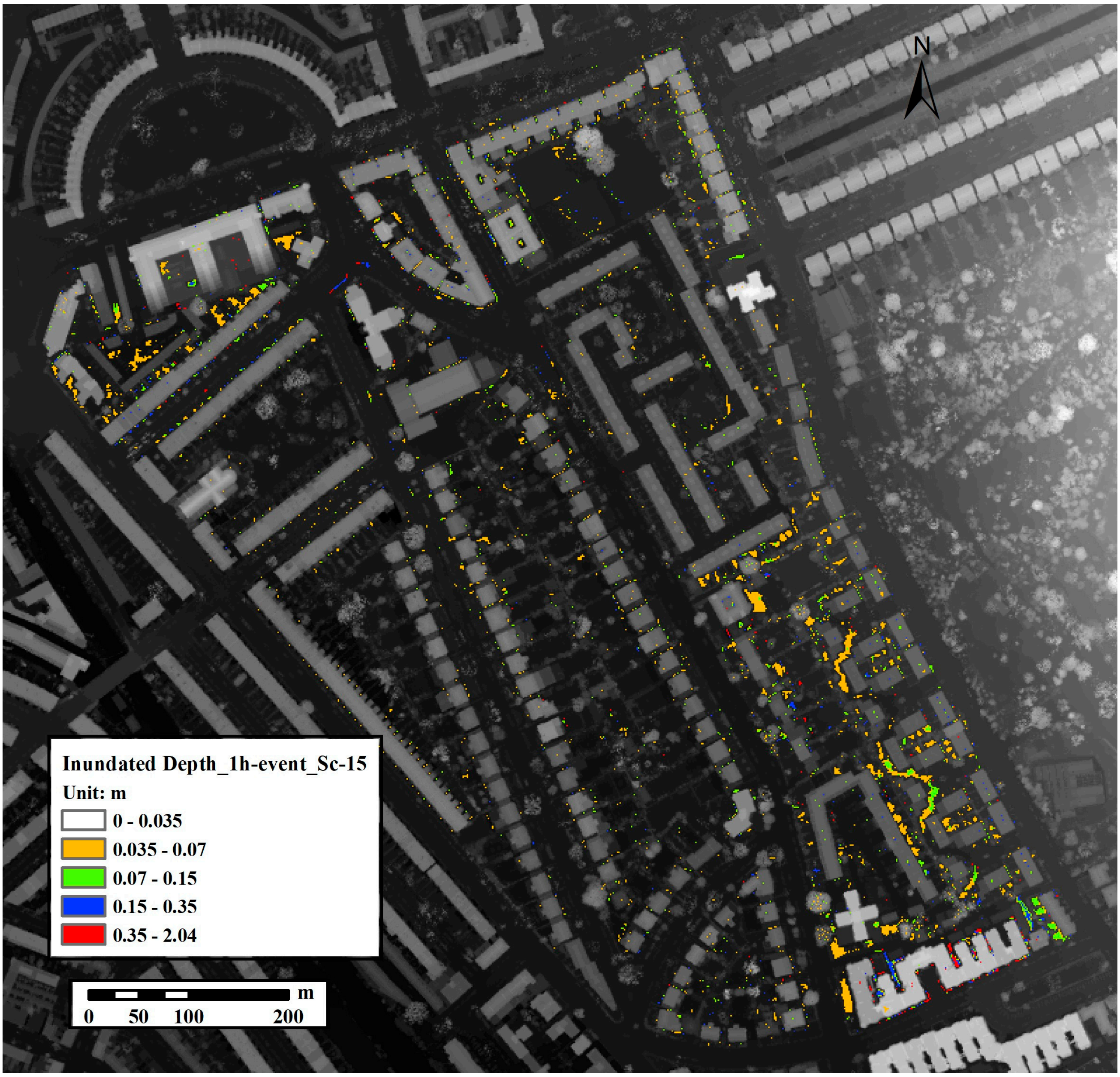

Fig. S44. Flood map of scenario 15 at the time of 2h (1-hour rainfall event)

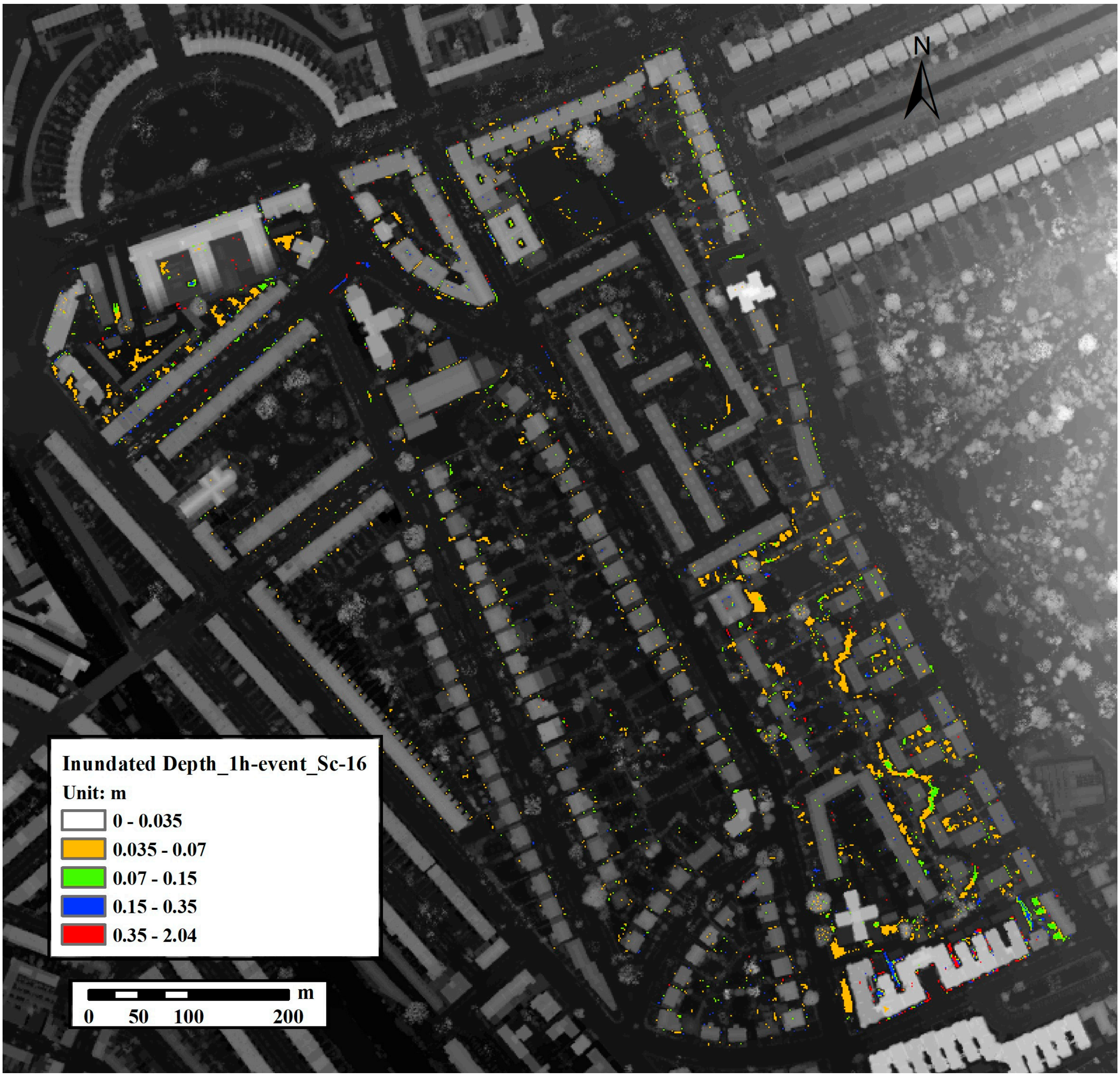

Fig. S45. Flood map of scenario 16 at the time of 2h (1-hour rainfall event)

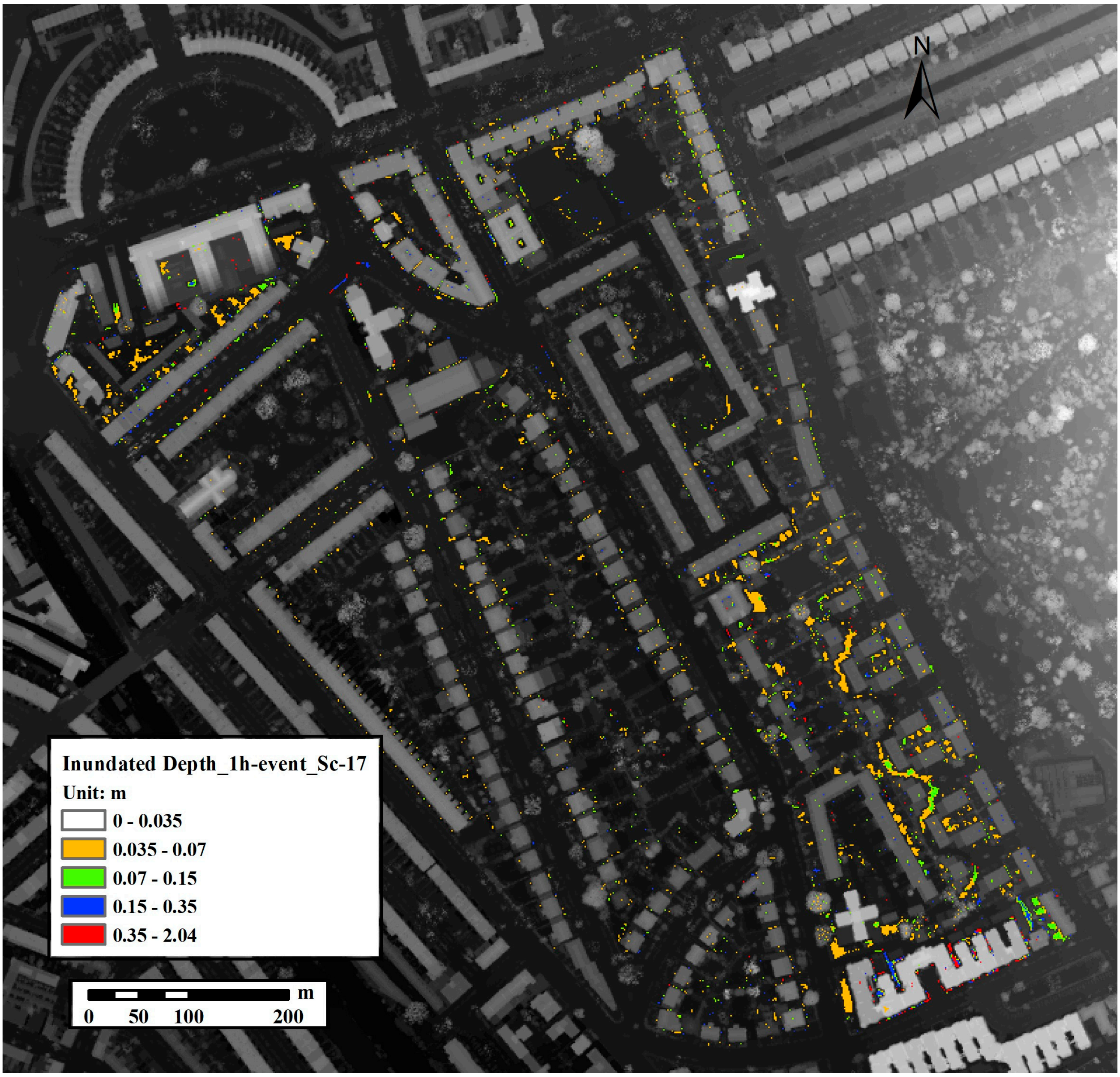

Fig. S46. Flood map of scenario 17 at the time of 2h (1-hour rainfall event)

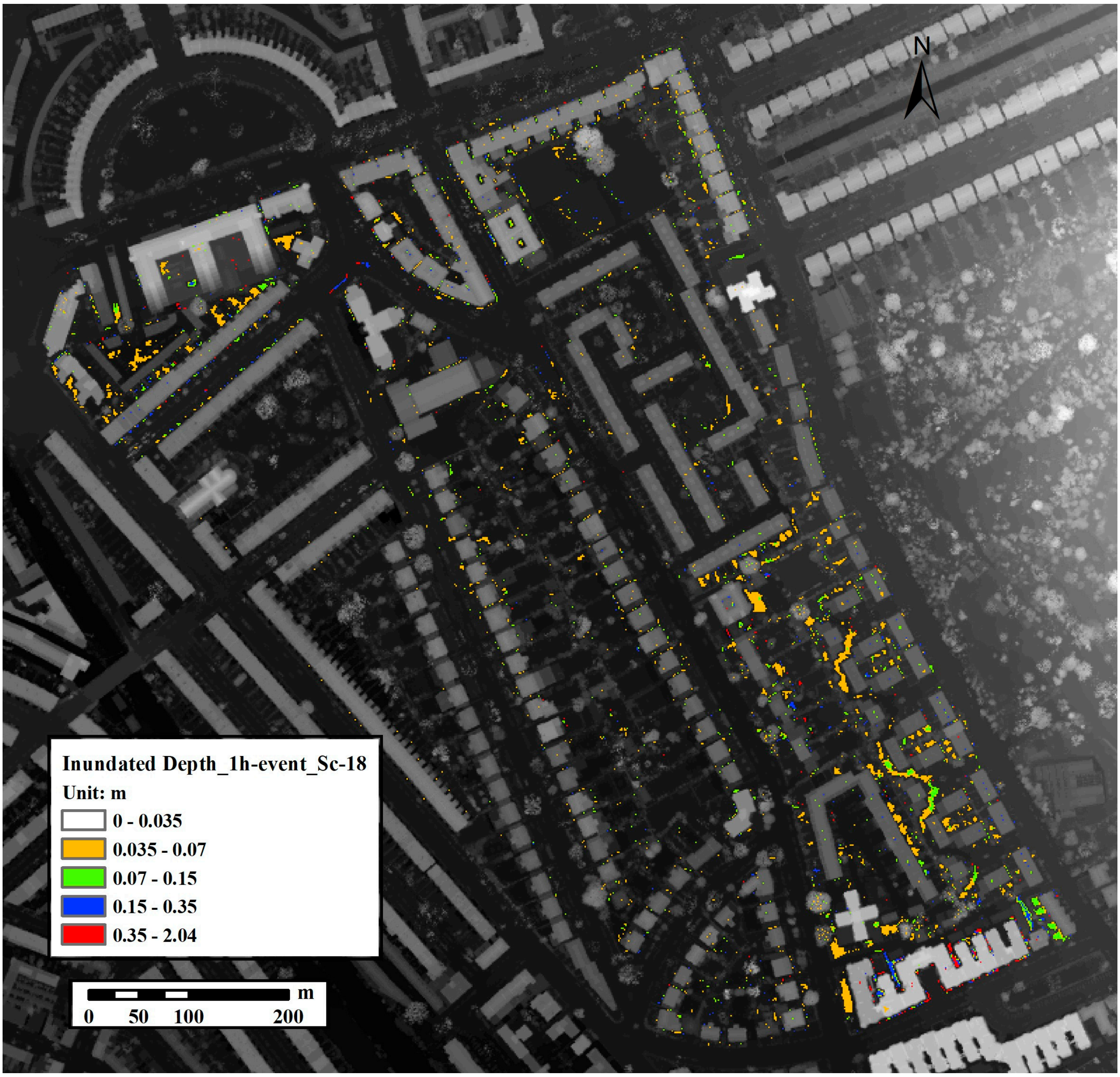

Fig. S47. Flood map of scenario 18 at the time of 2h (1-hour rainfall event)

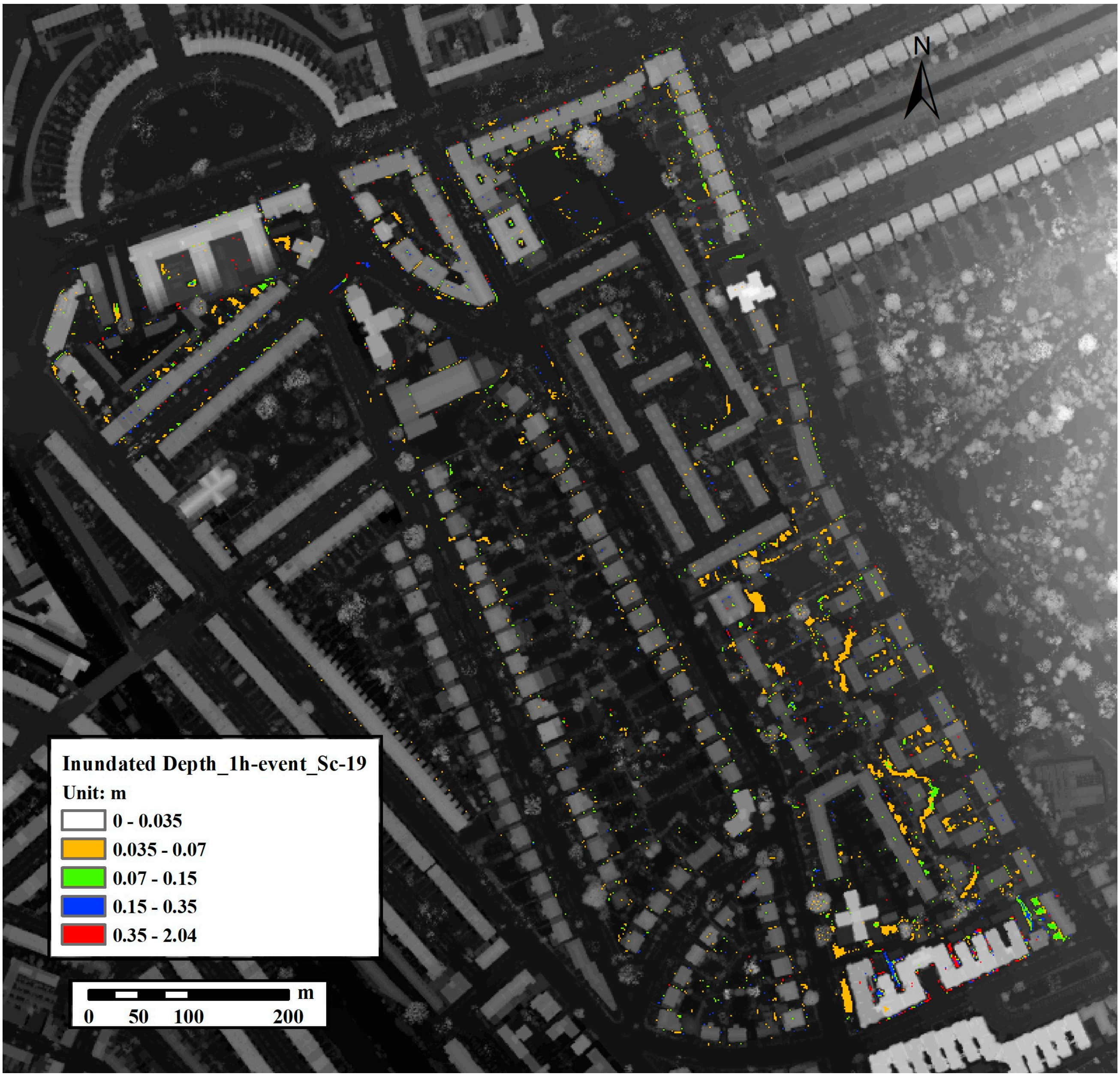

Fig. S48. Flood map of scenario 19 at the time of 2h (1-hour rainfall event)

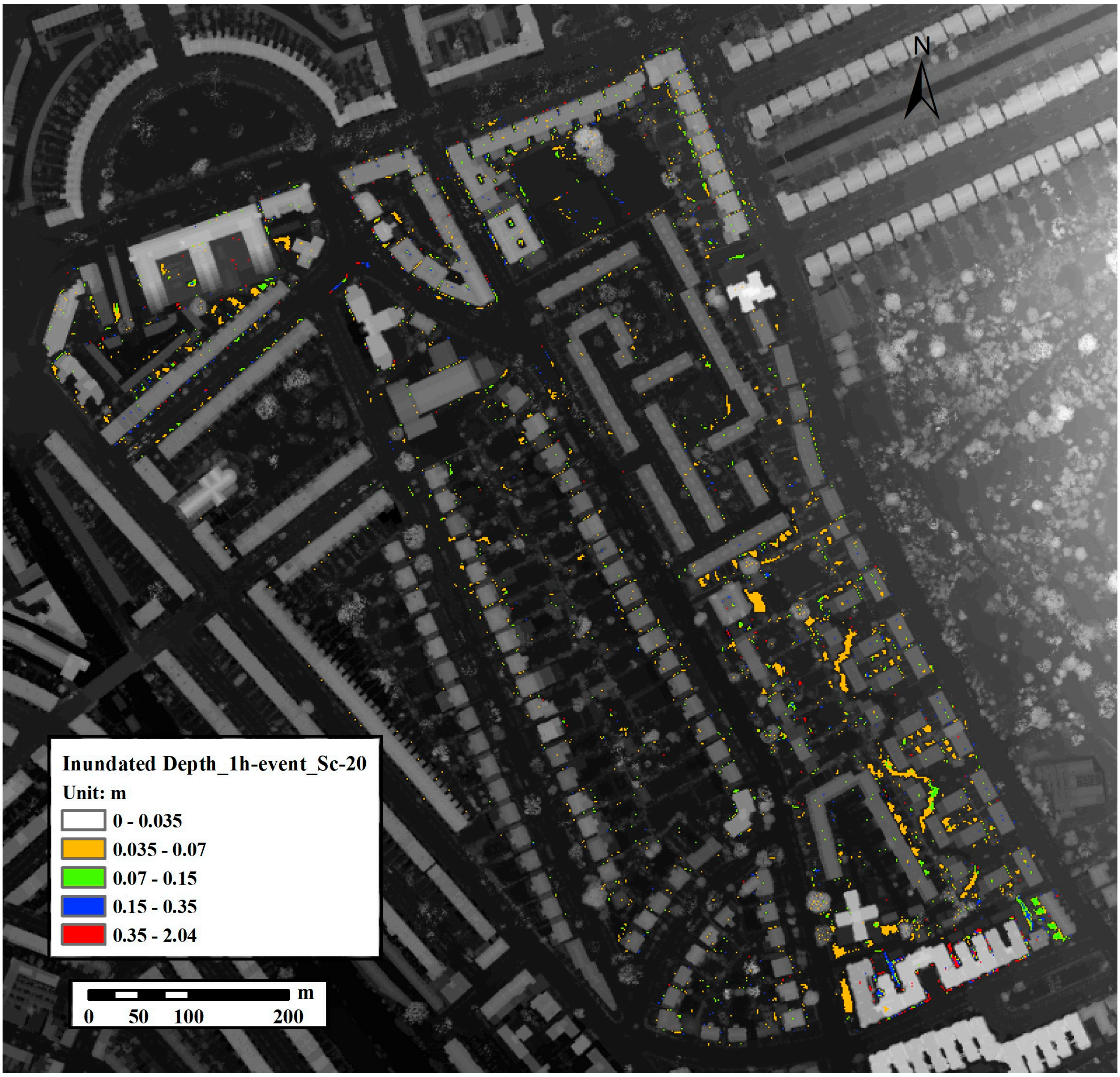

Fig. S49. Flood map of scenario 20 at the time of 2h (1-hour rainfall event)

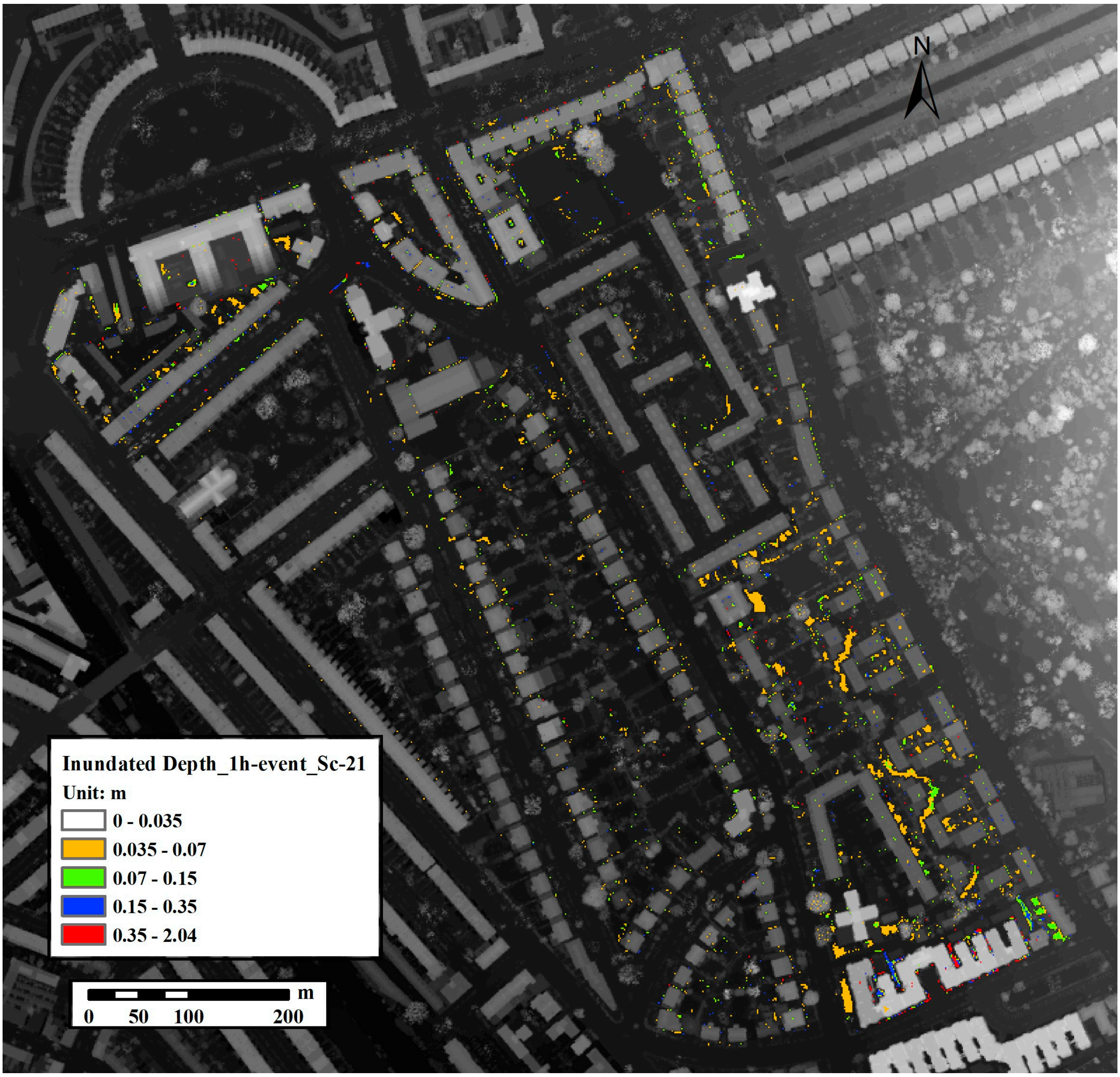

Fig. S50. Flood map of scenario 21 at the time of 2h (1-hour rainfall event)

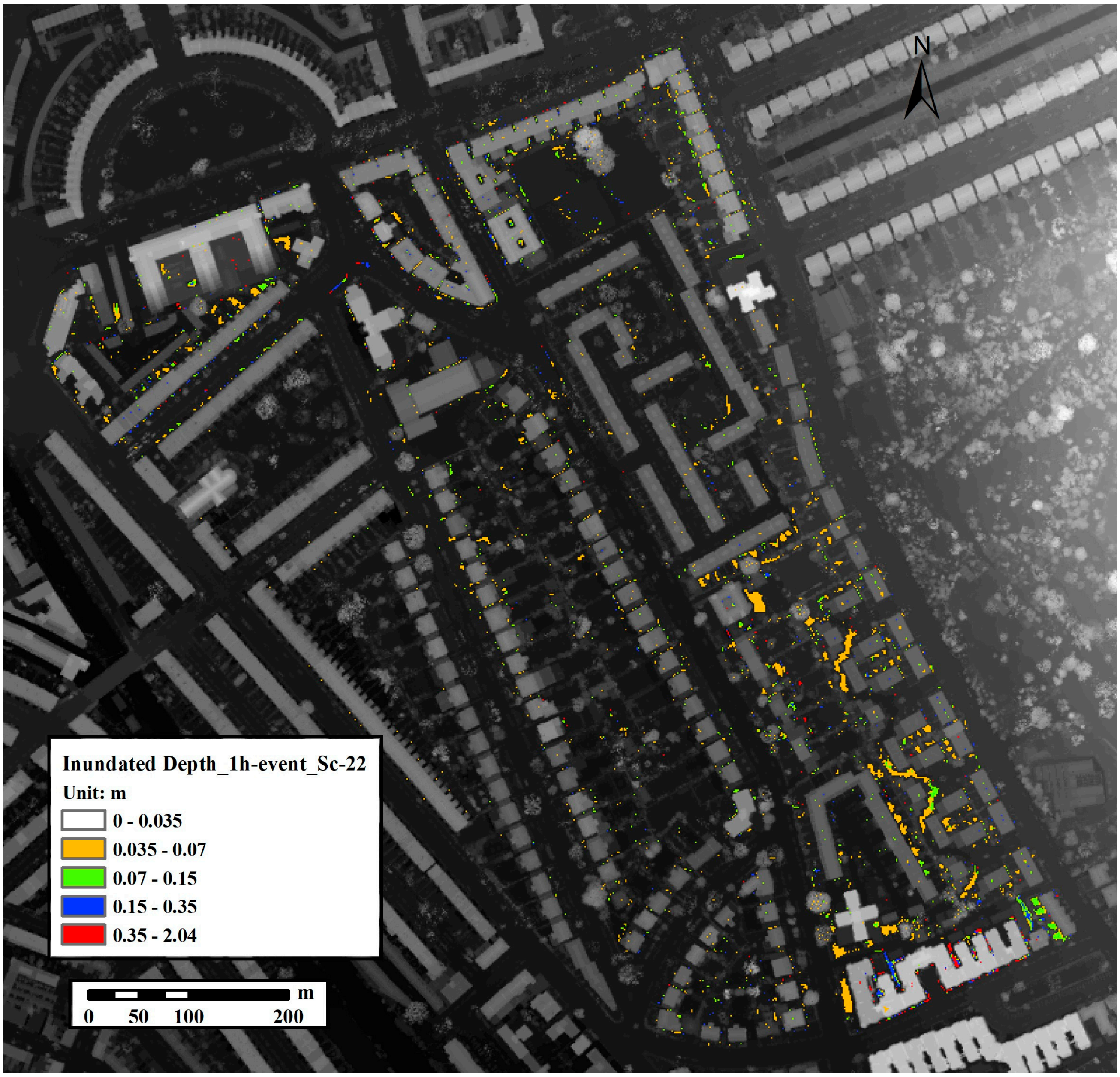

Fig. S51. Flood map of scenario 22 at the time of 2h (1-hour rainfall event)

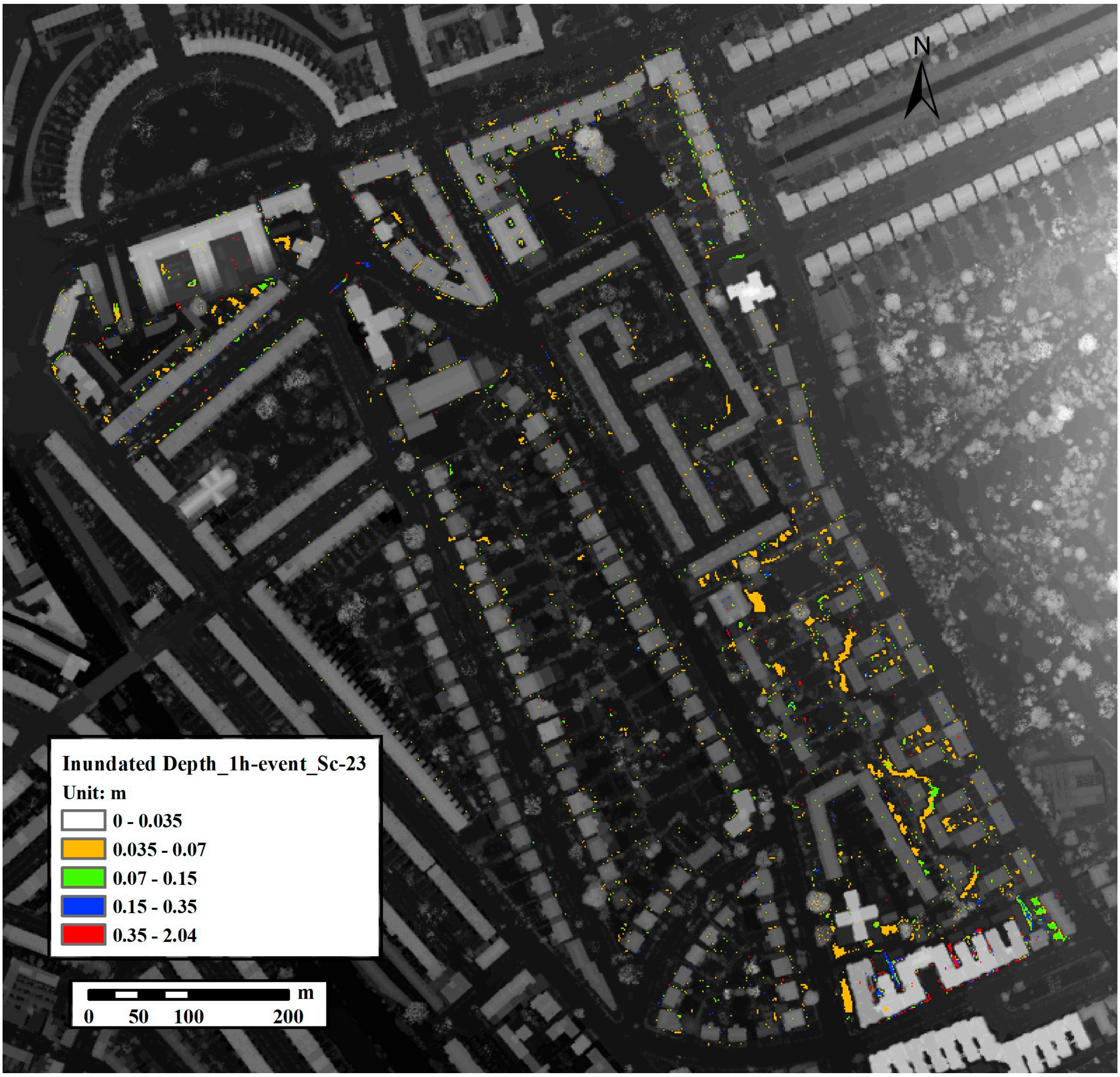

Fig. S52. Flood map of scenario 23 at the time of 2h (1-hour rainfall event)

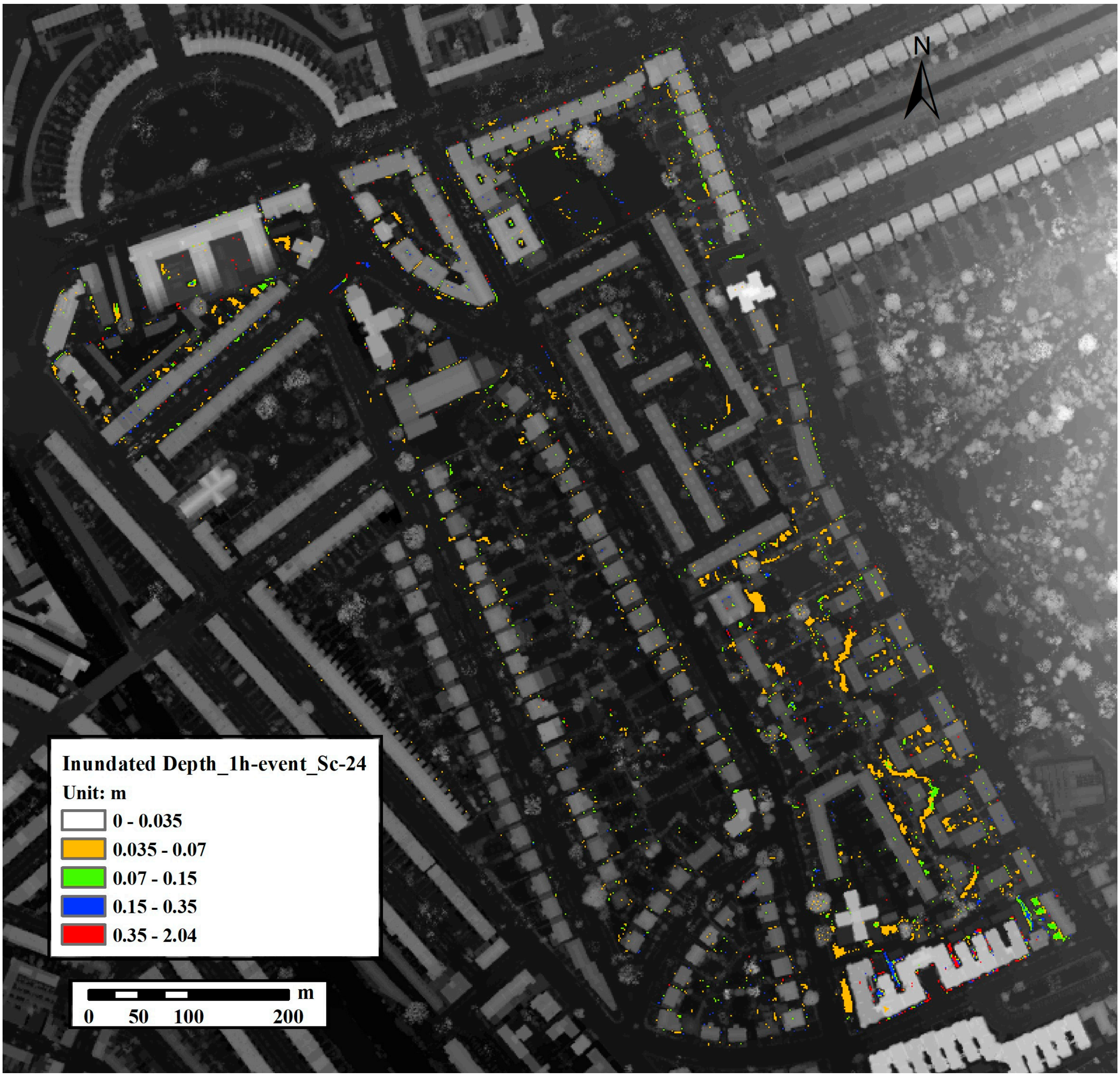

Fig. S53. Flood map of scenario 24 at the time of 2h (1-hour rainfall event)

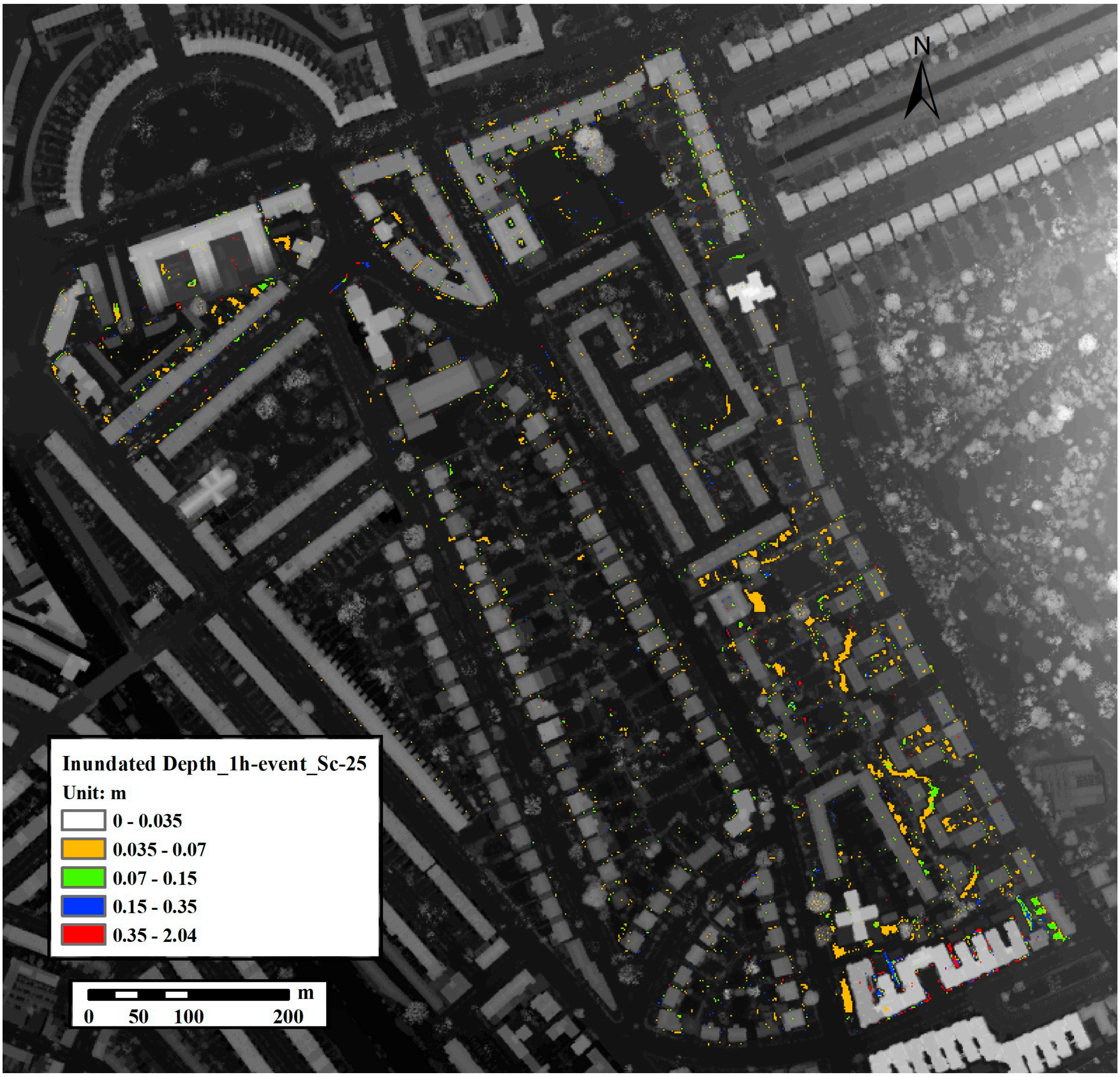

Fig. S54. Flood map of scenario 25 at the time of 2h (1-hour rainfall event)

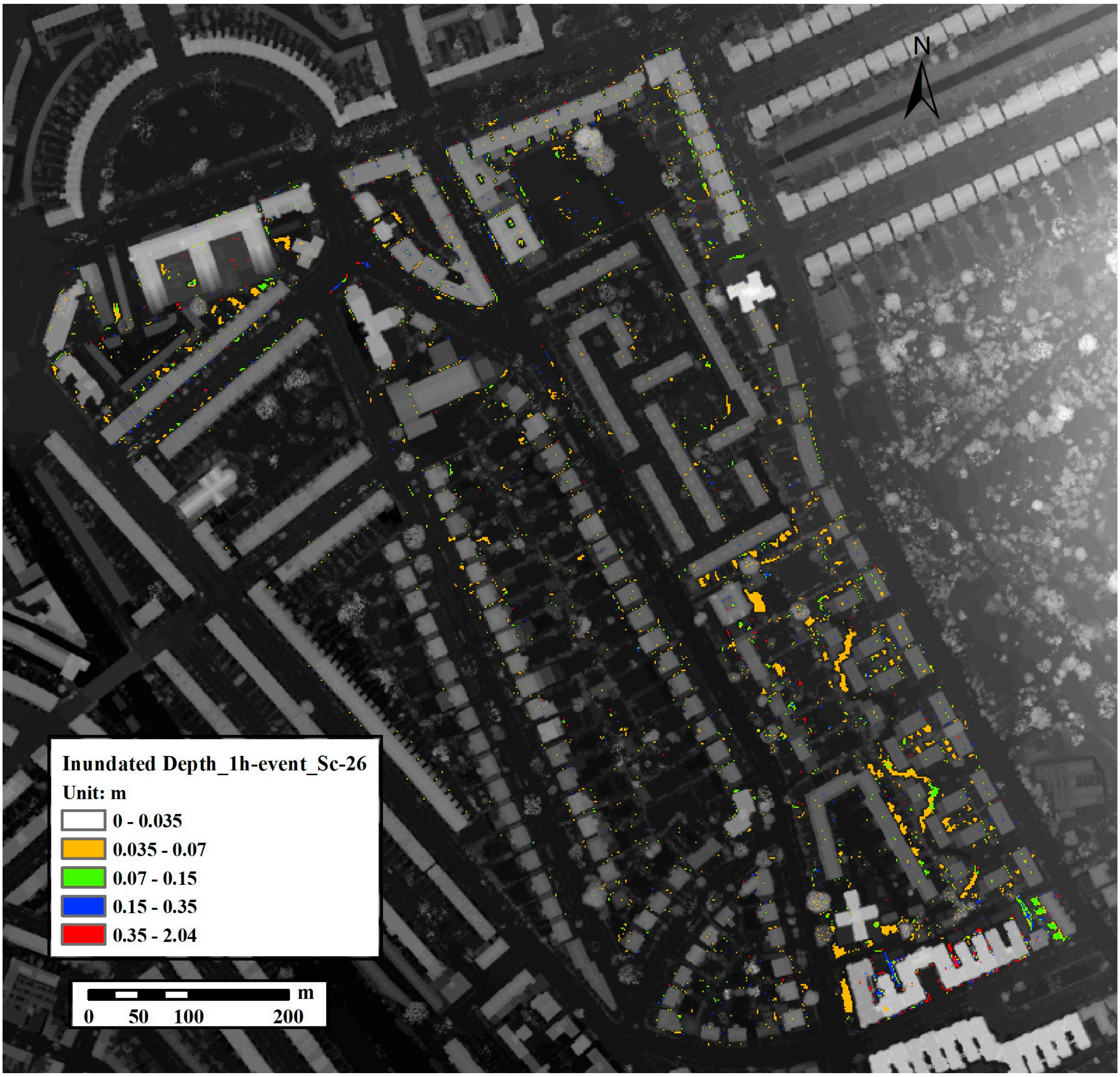

Fig. S55. Flood map of scenario 26 at the time of 2h (1-hour rainfall event)

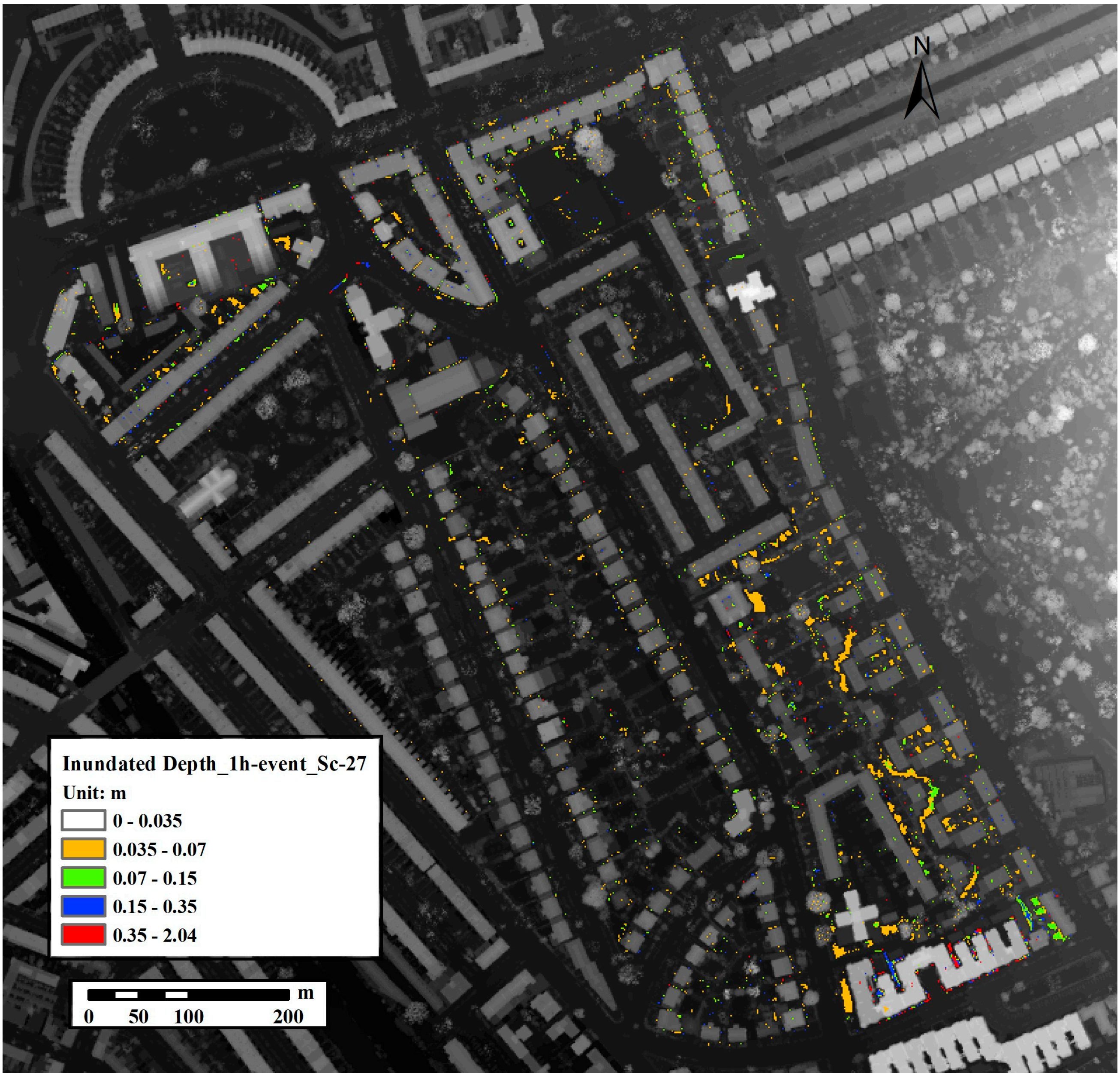

Fig. S56. Flood map of scenario 27 at the time of 2h (1-hour rainfall event)

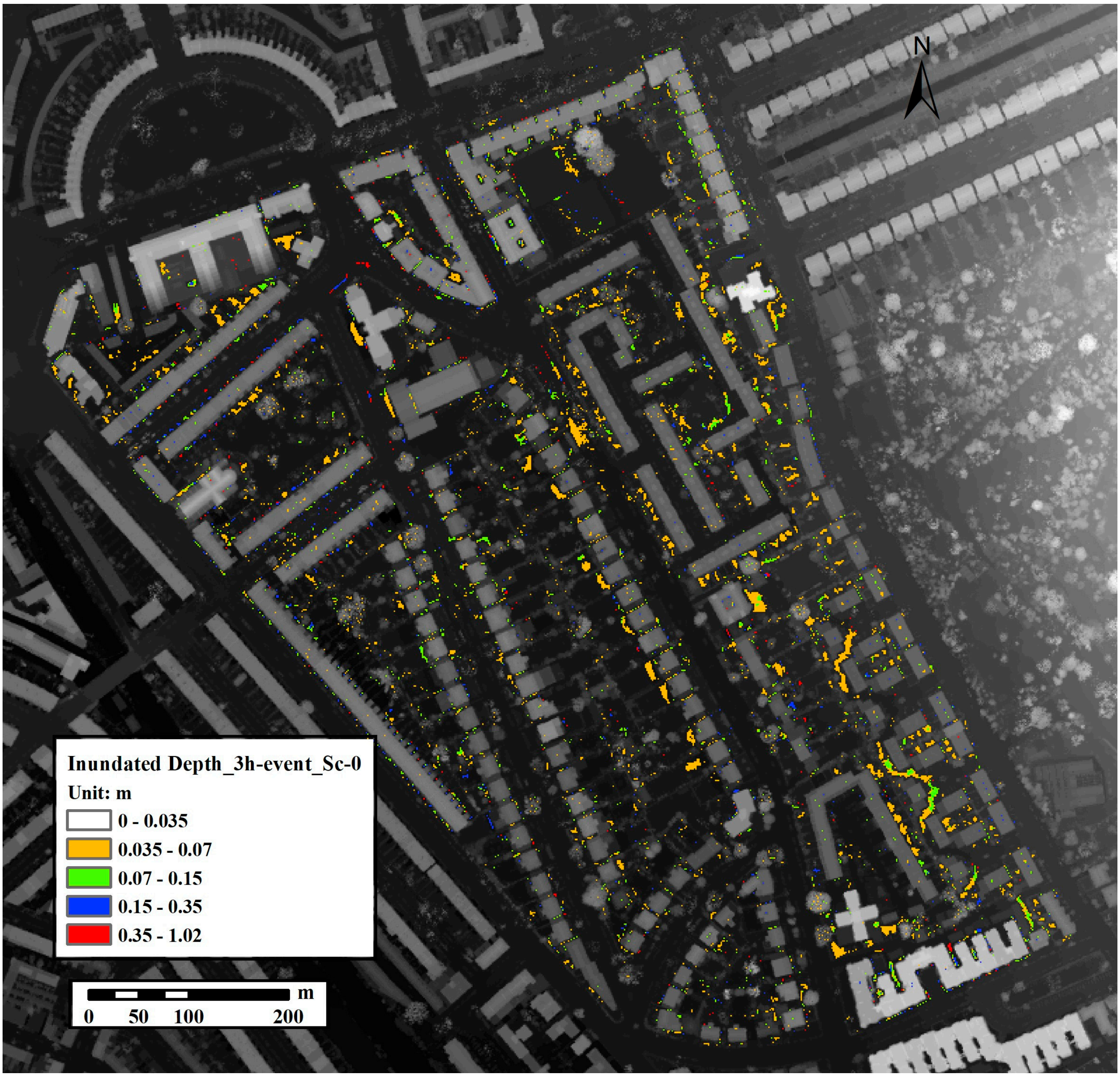

Fig. S57. Flood map of scenario 0 at the time of 4h (3-hour rainfall event)

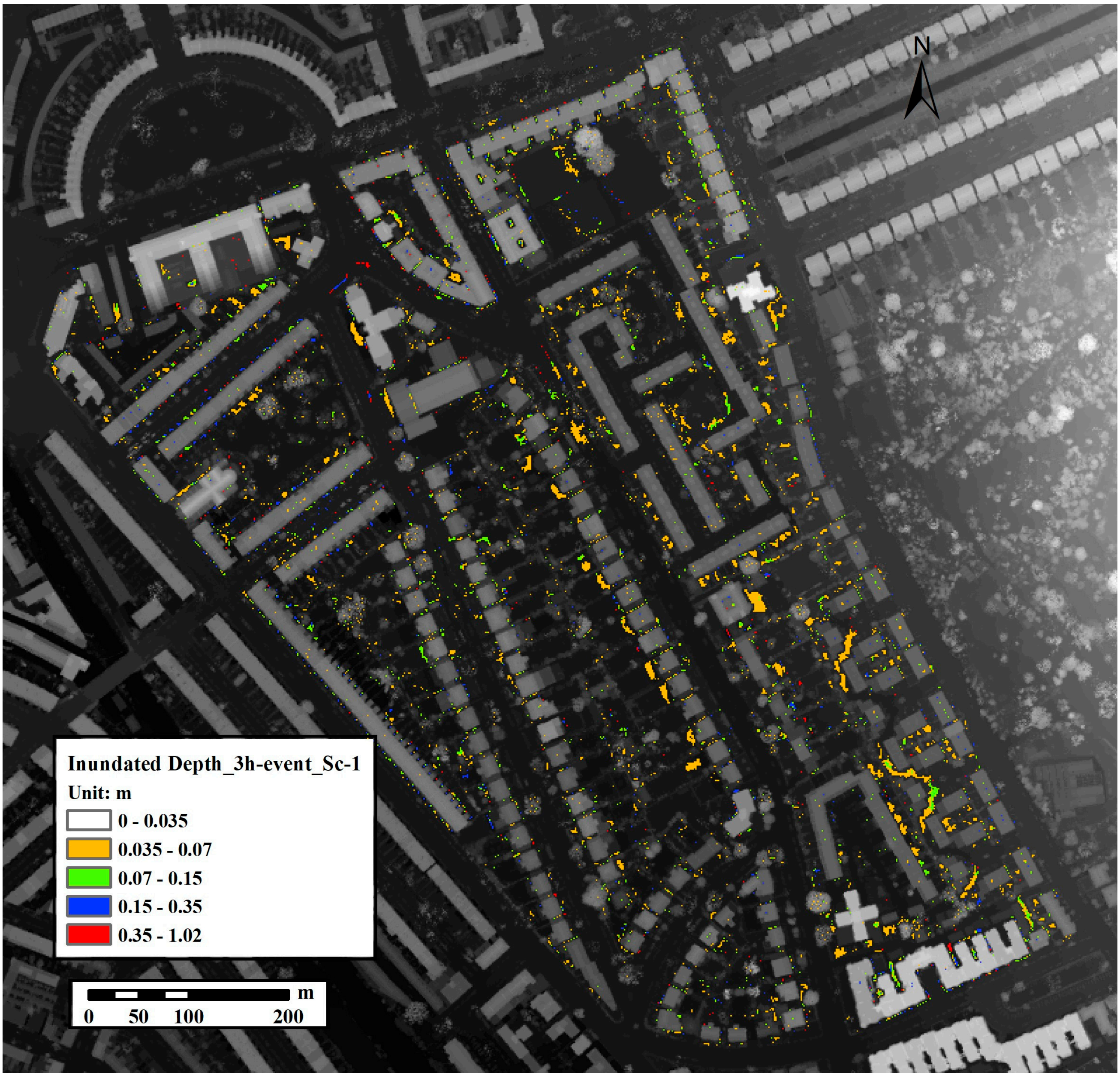

Fig. S58. Flood map of scenario 1 at the time of 4h (3-hour rainfall event)

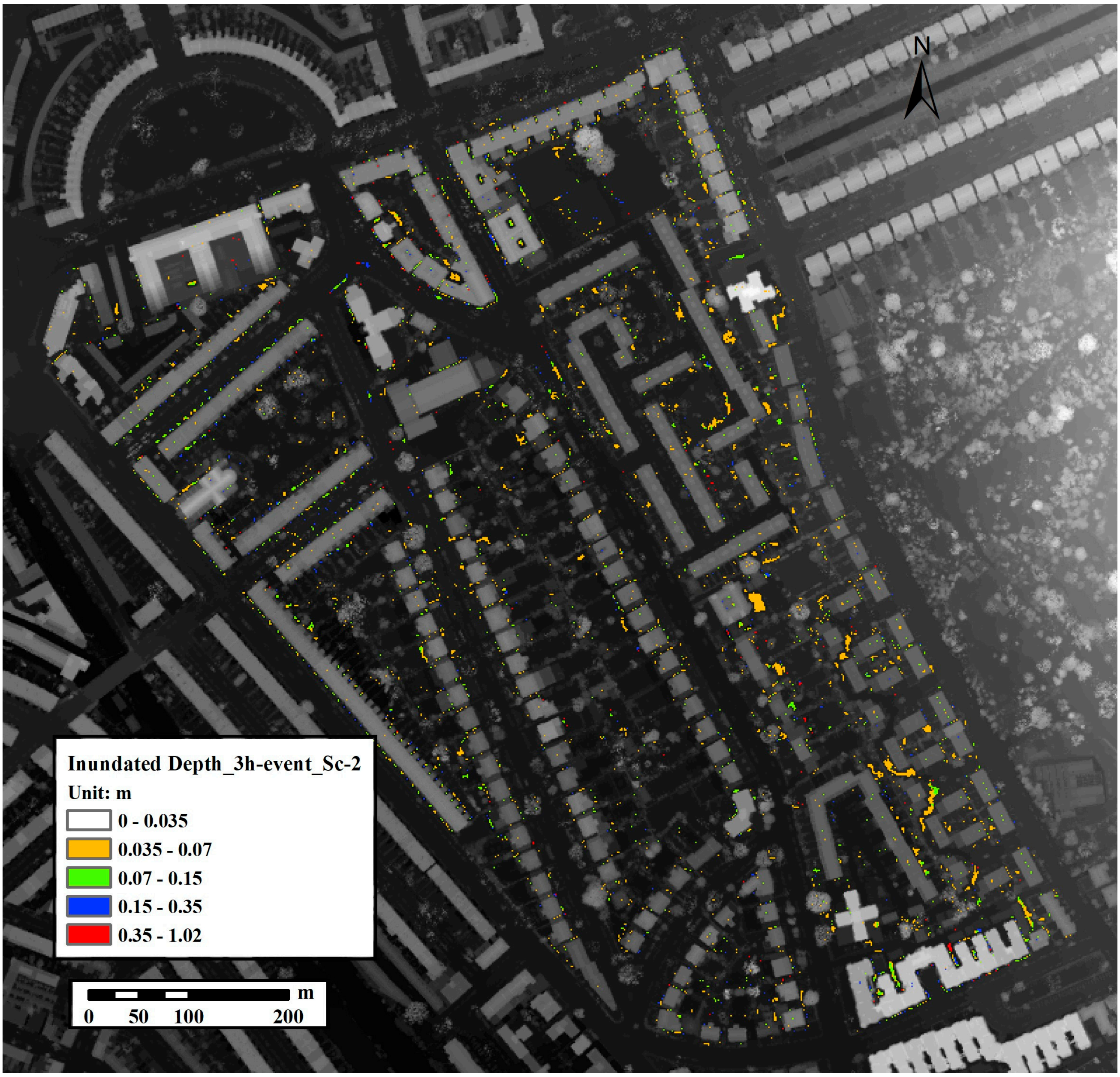

Fig. S59. Flood map of scenario 2 at the time of 4h (3-hour rainfall event)

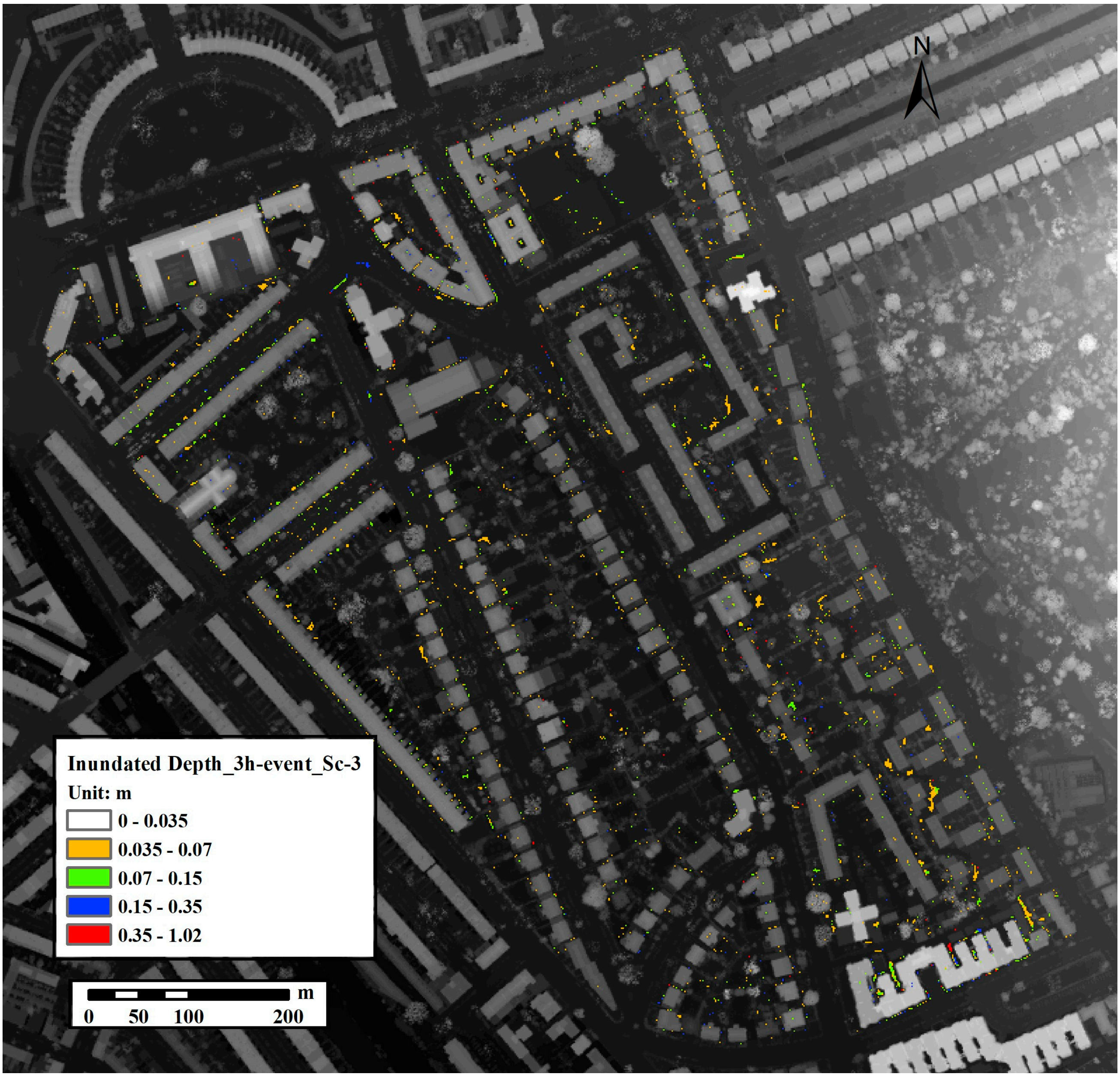

Fig. S60. Flood map of scenario 3 at the time of 4h (3-hour rainfall event)

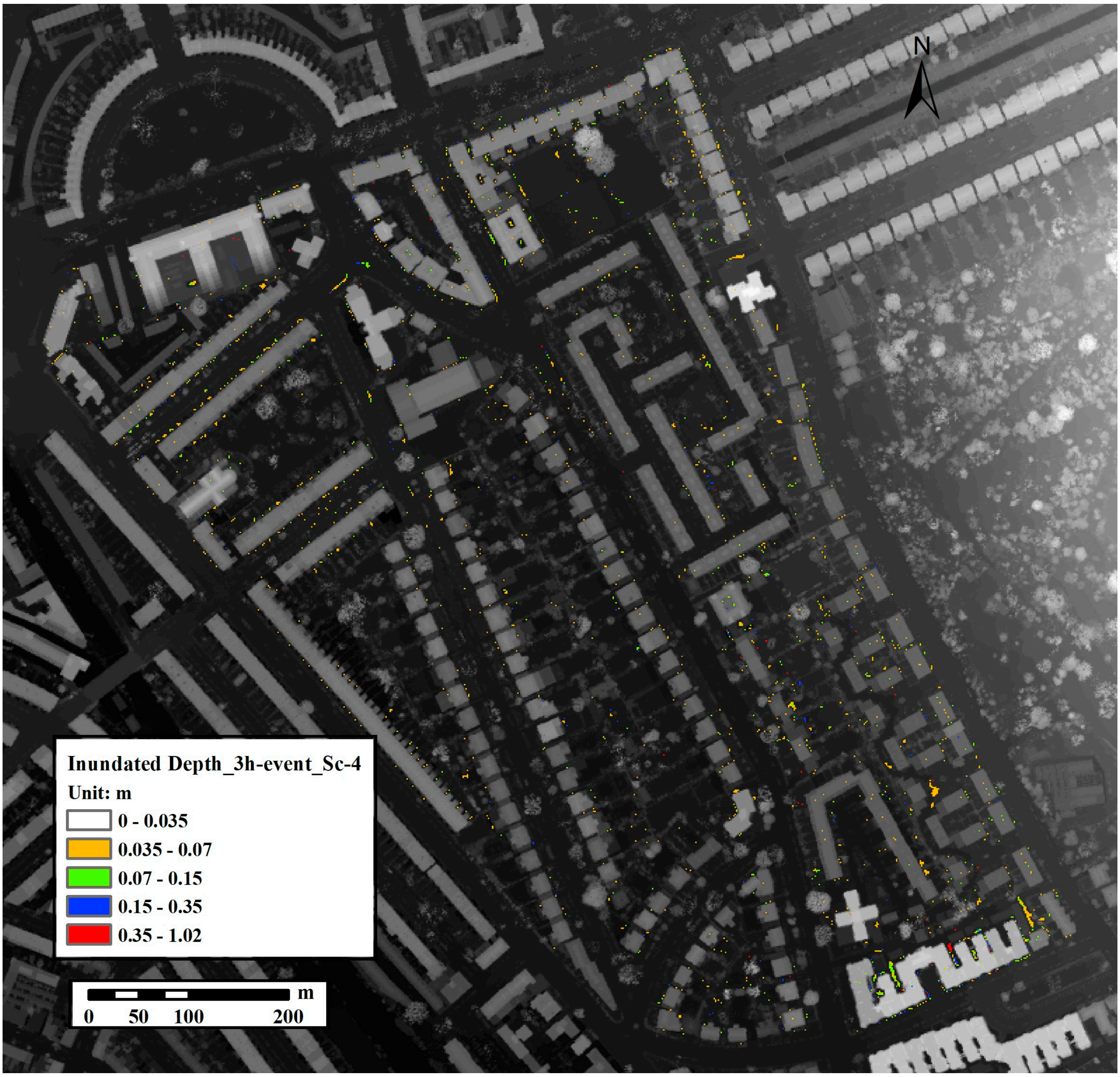

Fig. S61. Flood map of scenario 4 at the time of 4h (3-hour rainfall event)

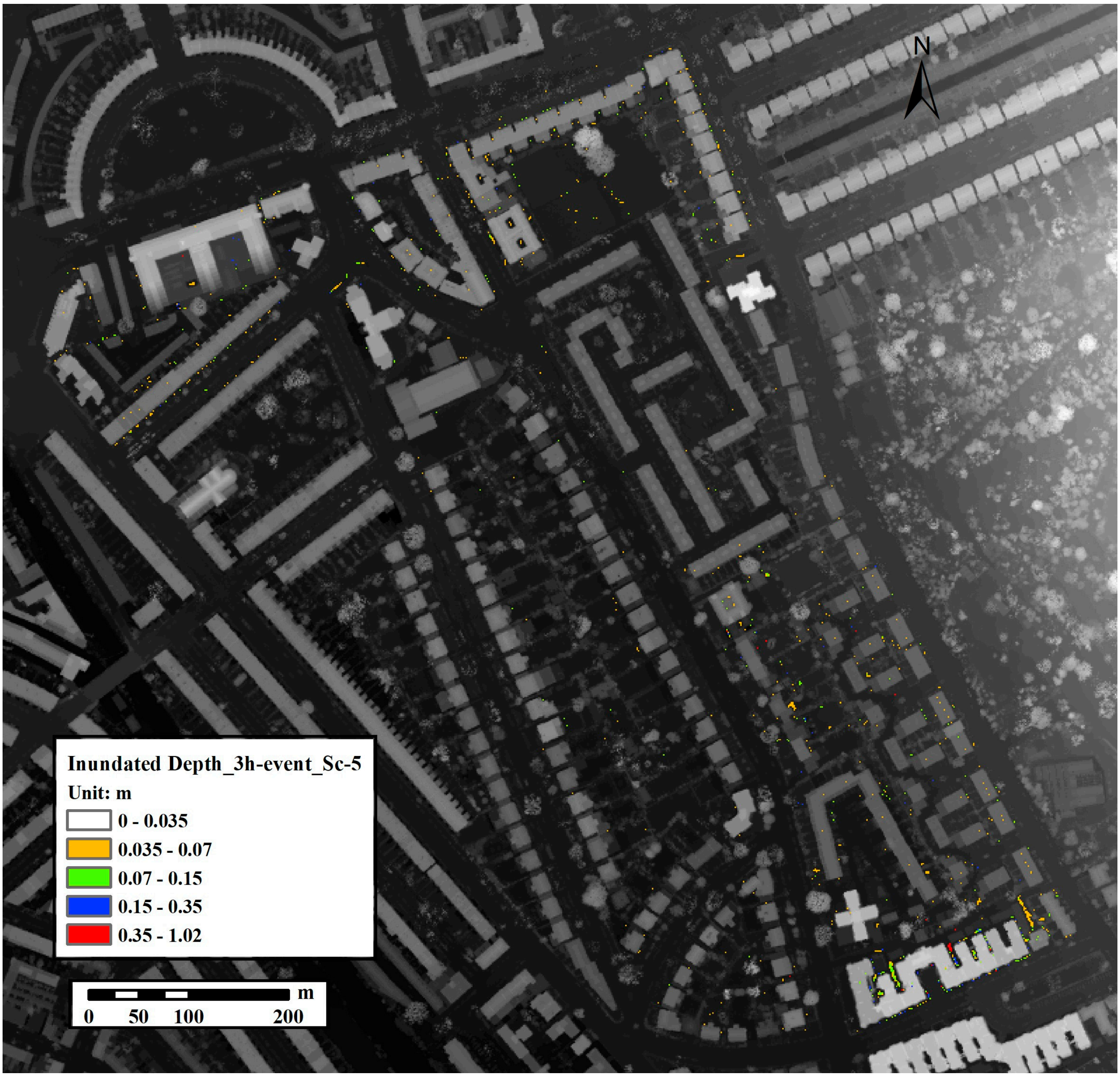

Fig. S62. Flood map of scenario 5 at the time of 4h (3-hour rainfall event)

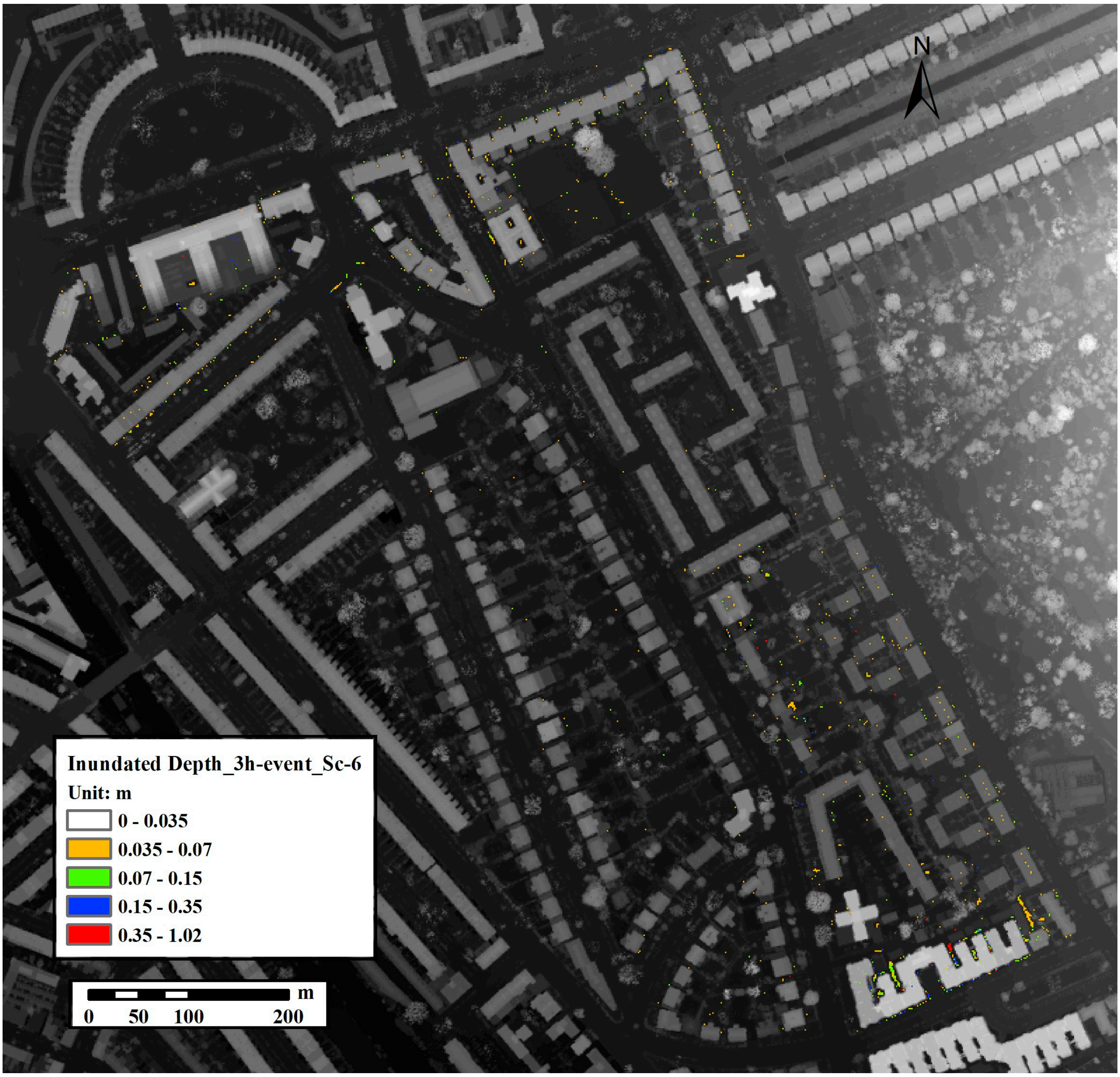

Fig. S63. Flood map of scenario 6 at the time of 4h (3-hour rainfall event)

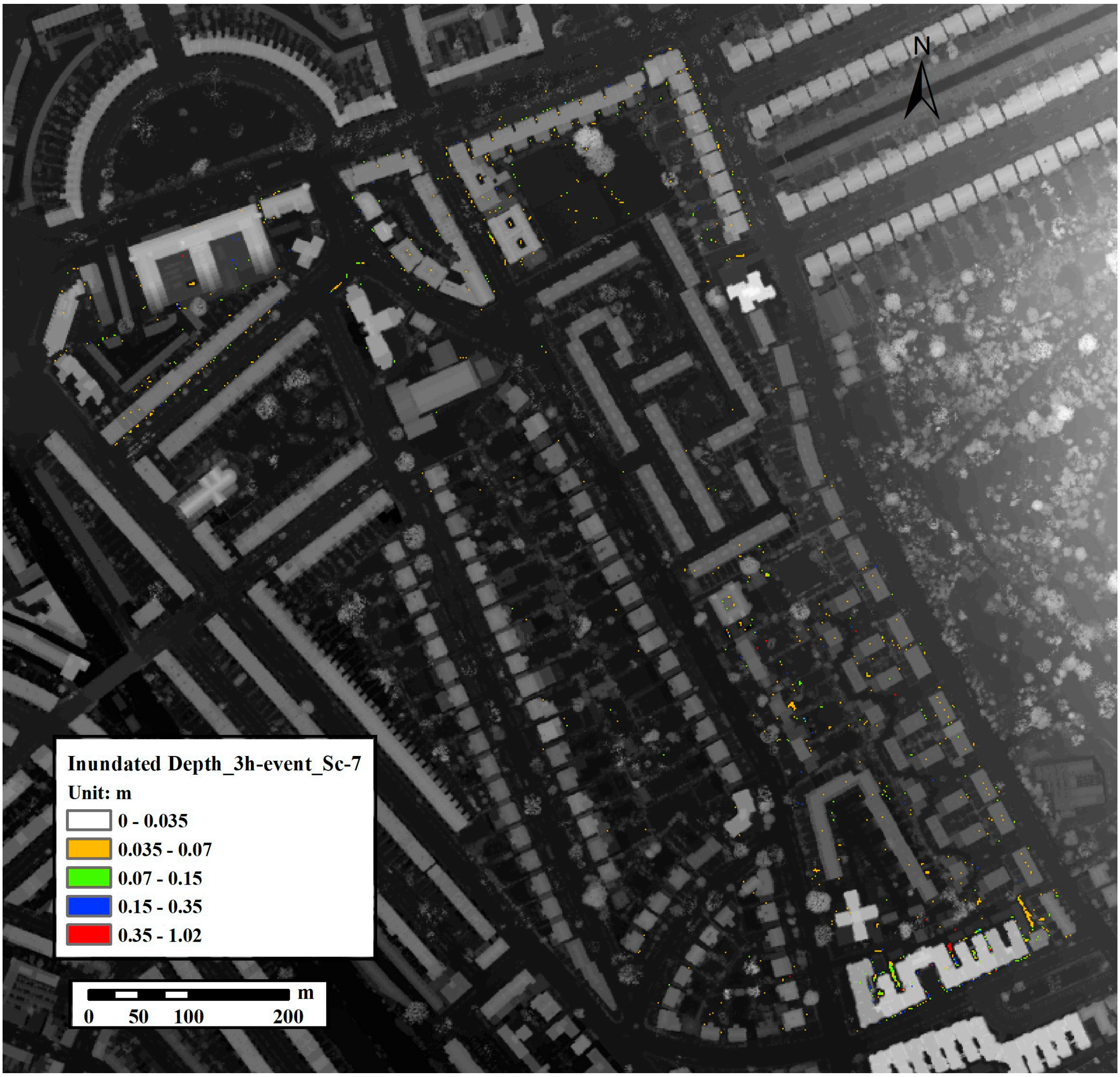

Fig. S64. Flood map of scenario 7 at the time of 4h (3-hour rainfall event)

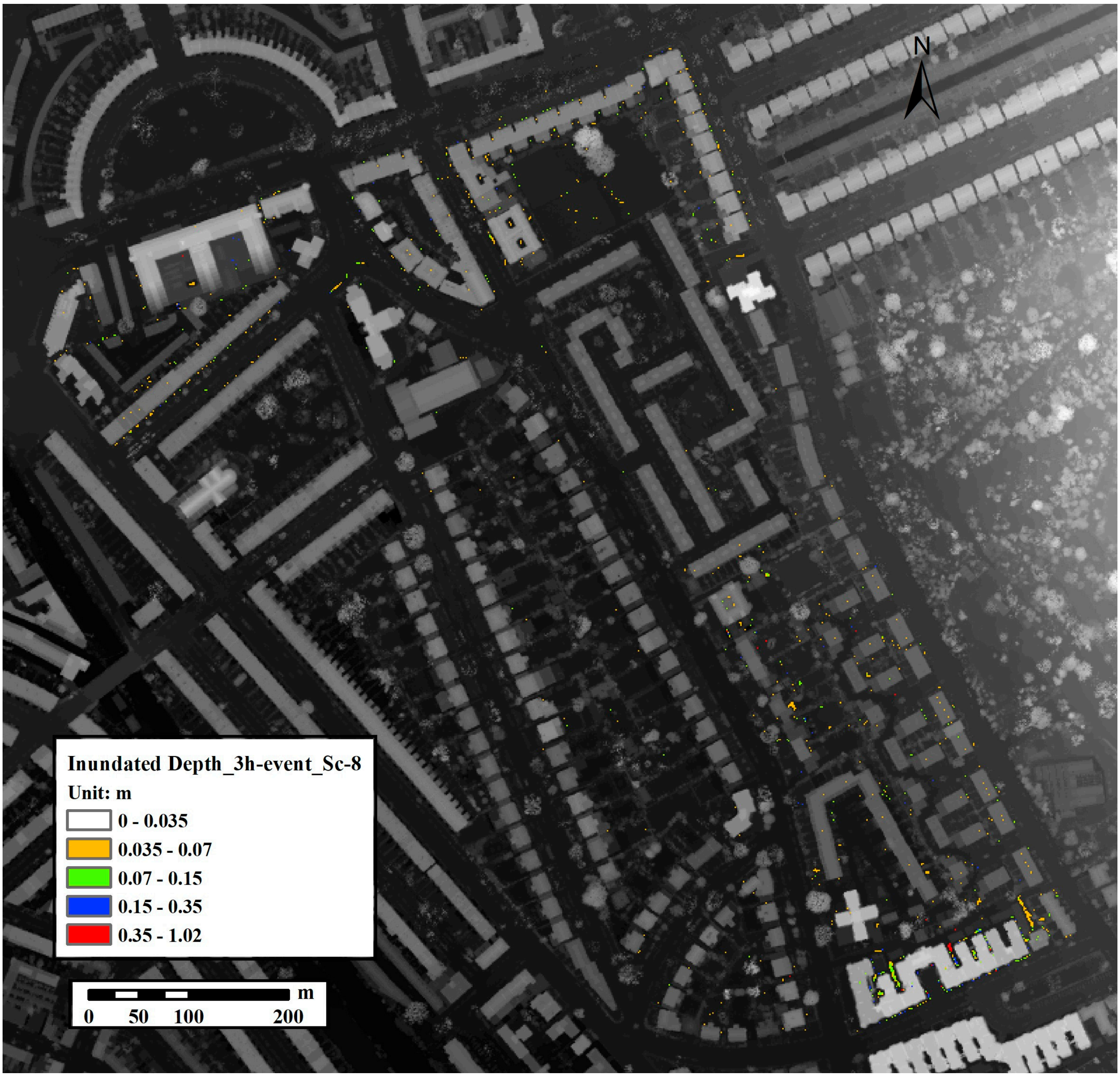

Fig. S65. Flood map of scenario 8 at the time of 4h (3-hour rainfall event)

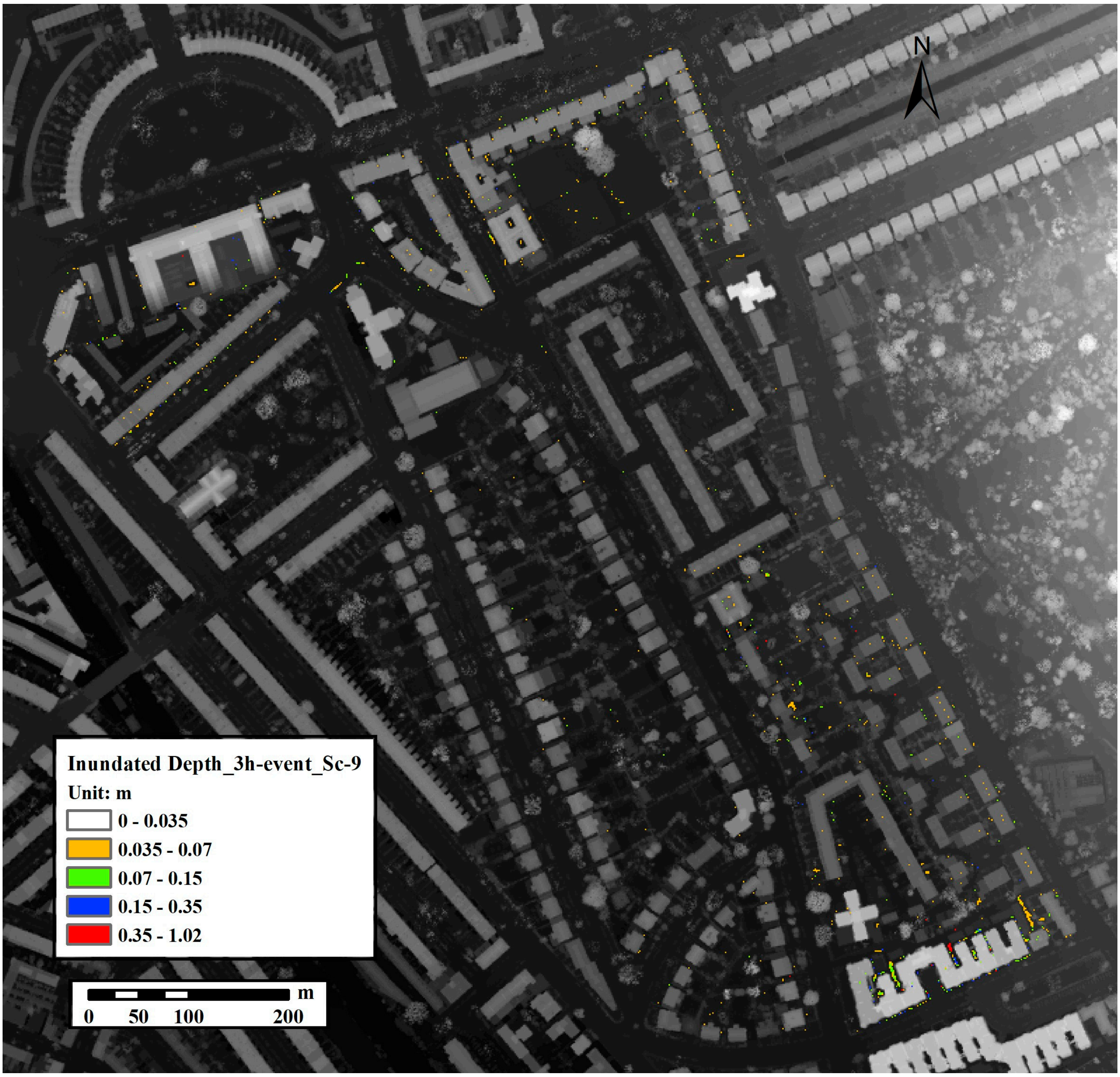

Fig. S66. Flood map of scenario 9 at the time of 4h (3-hour rainfall event)

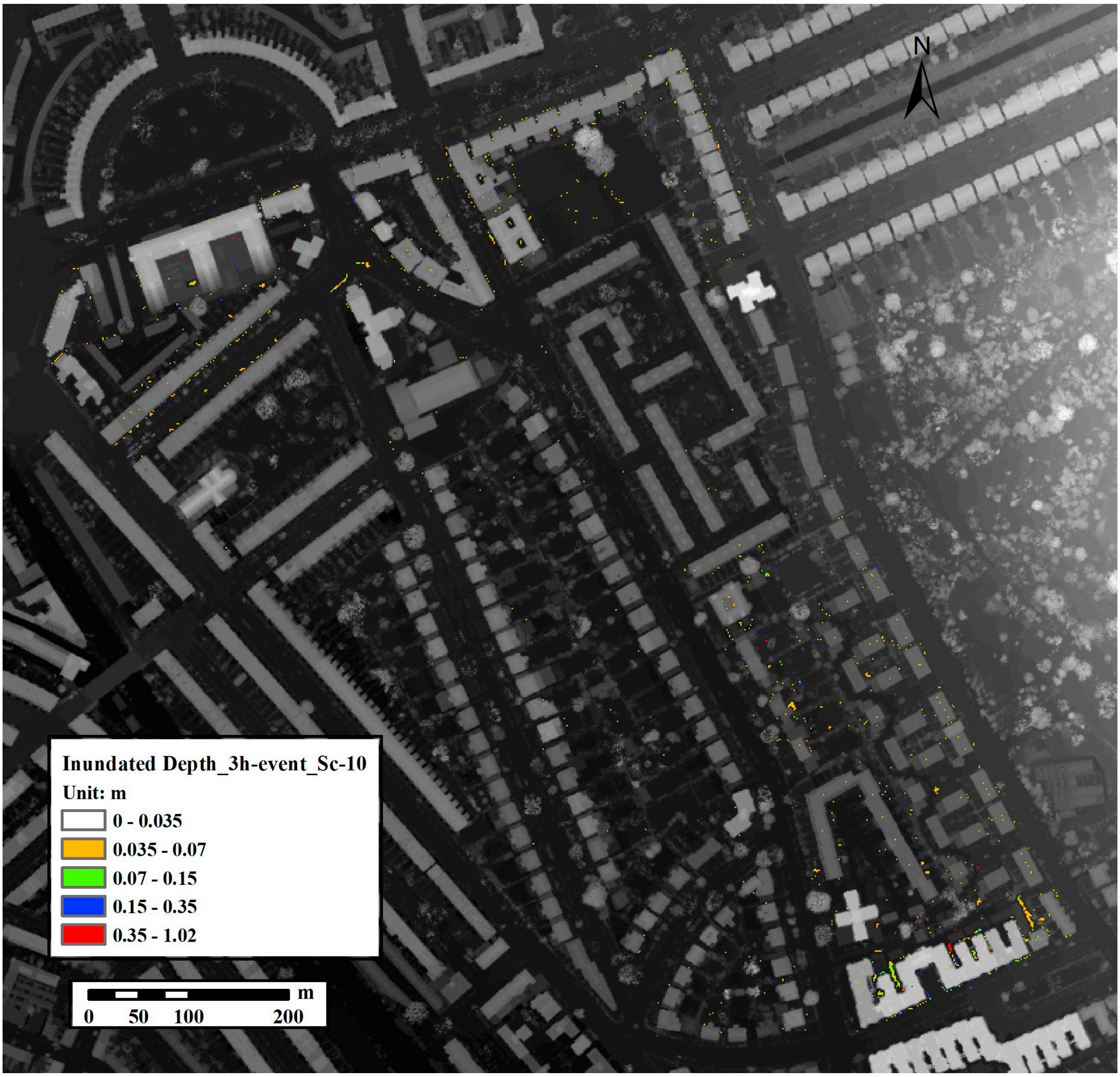

Fig. S67. Flood map of scenario 10 at the time of 4h (3-hour rainfall event)

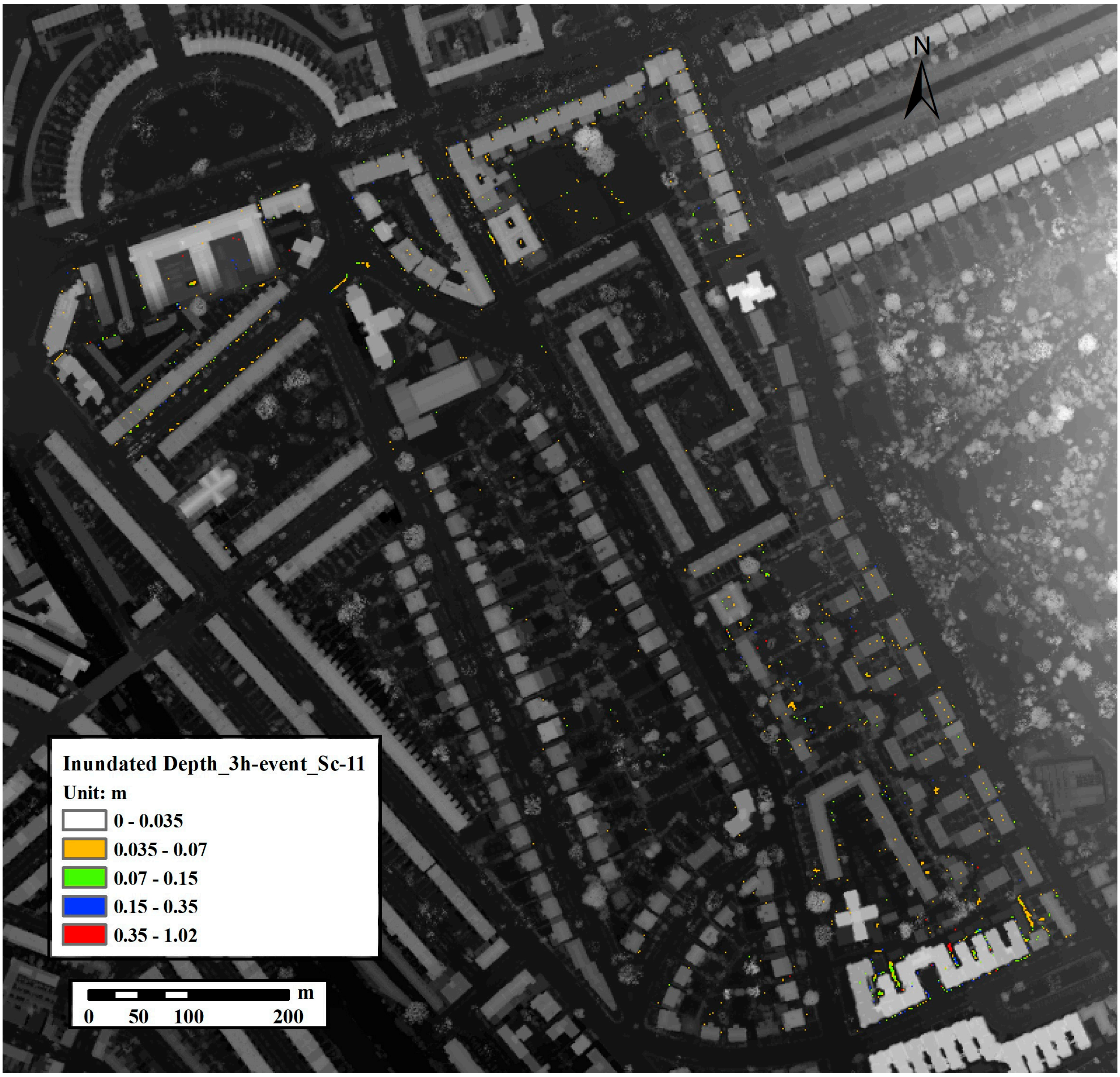

Fig. S68. Flood map of scenario 11 at the time of 4h (3-hour rainfall event)

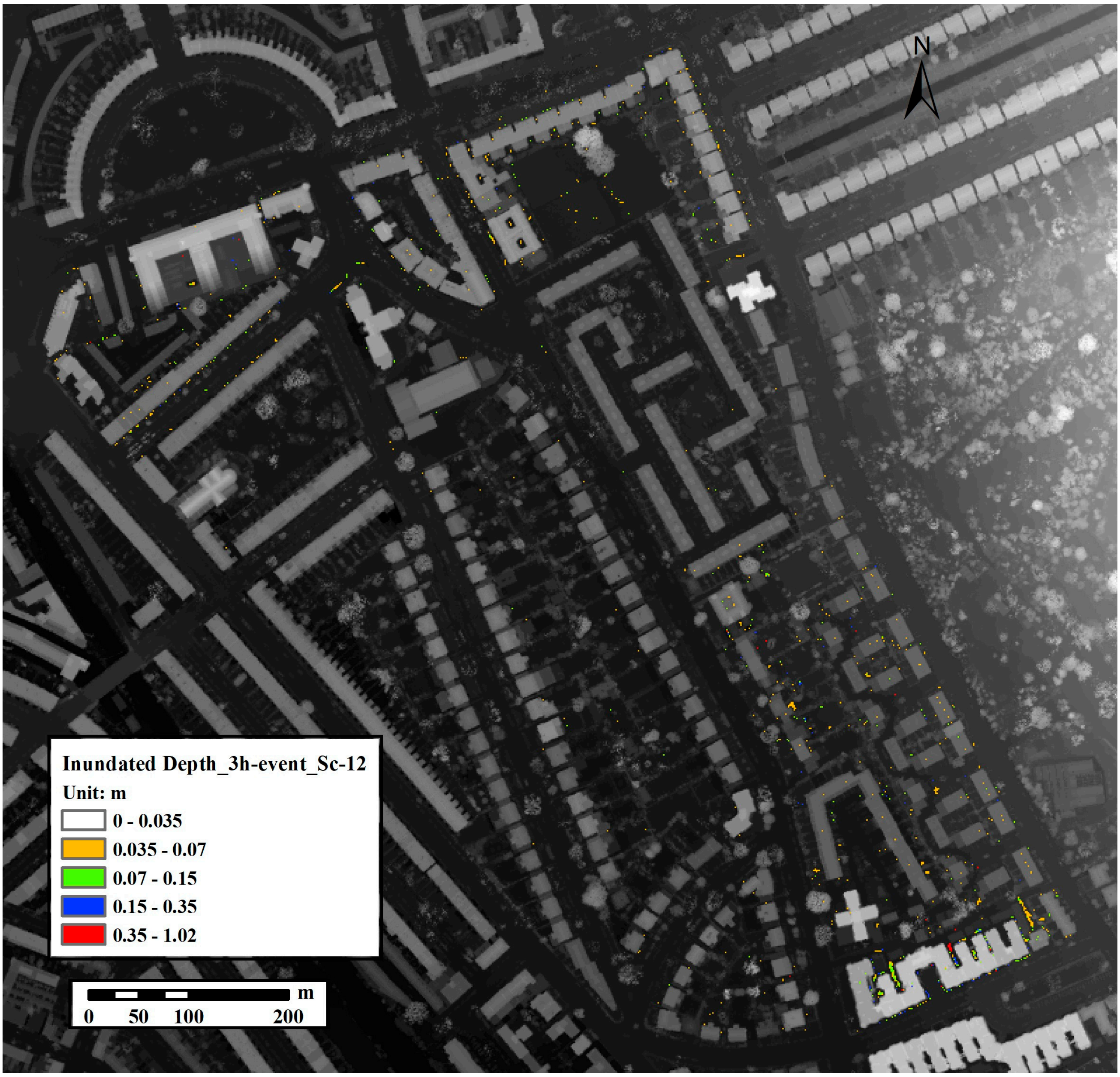

Fig. S69. Flood map of scenario 12 at the time of 4h (3-hour rainfall event)

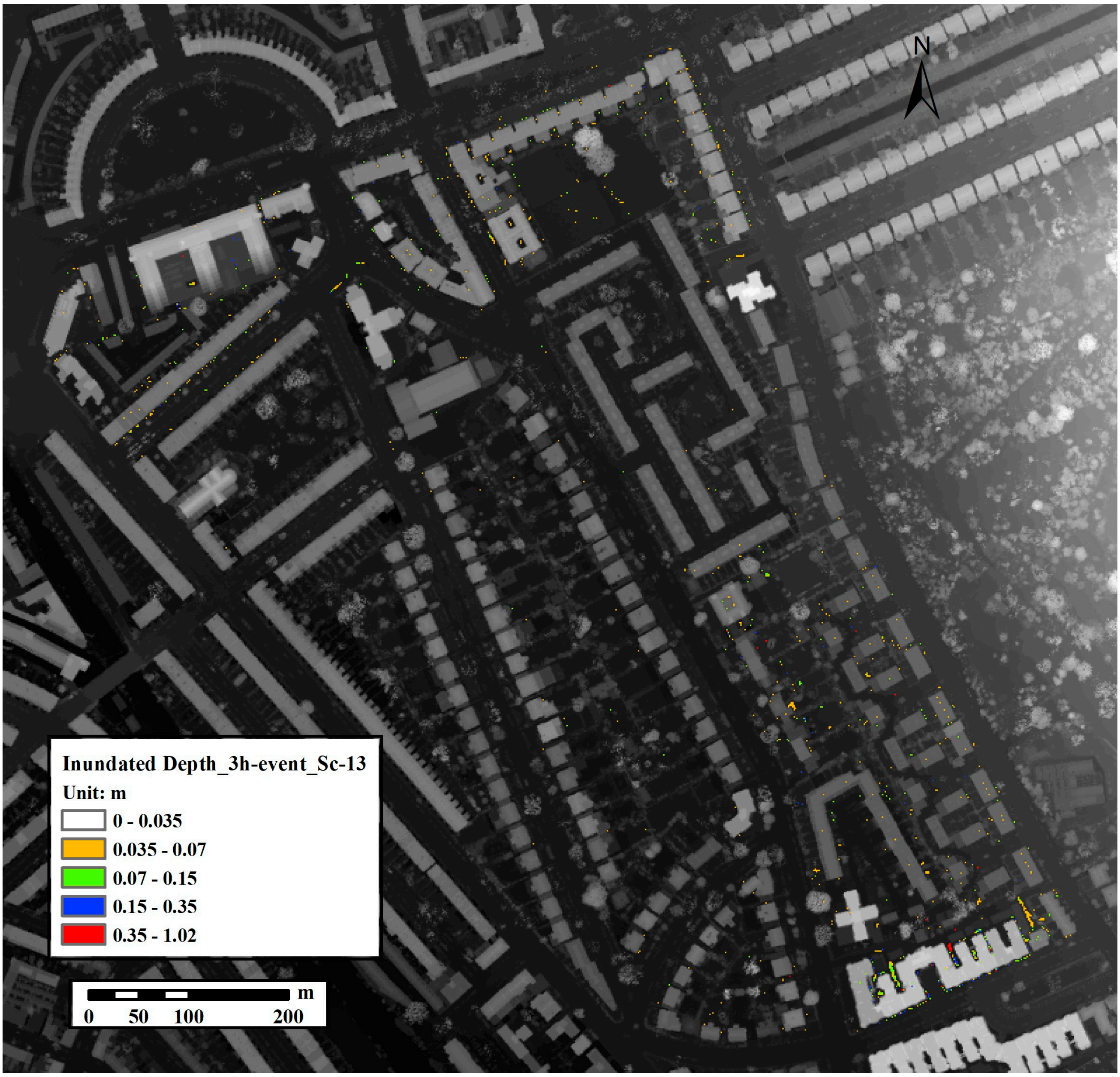

Fig. S70. Flood map of scenario 13 at the time of 4h (3-hour rainfall event)

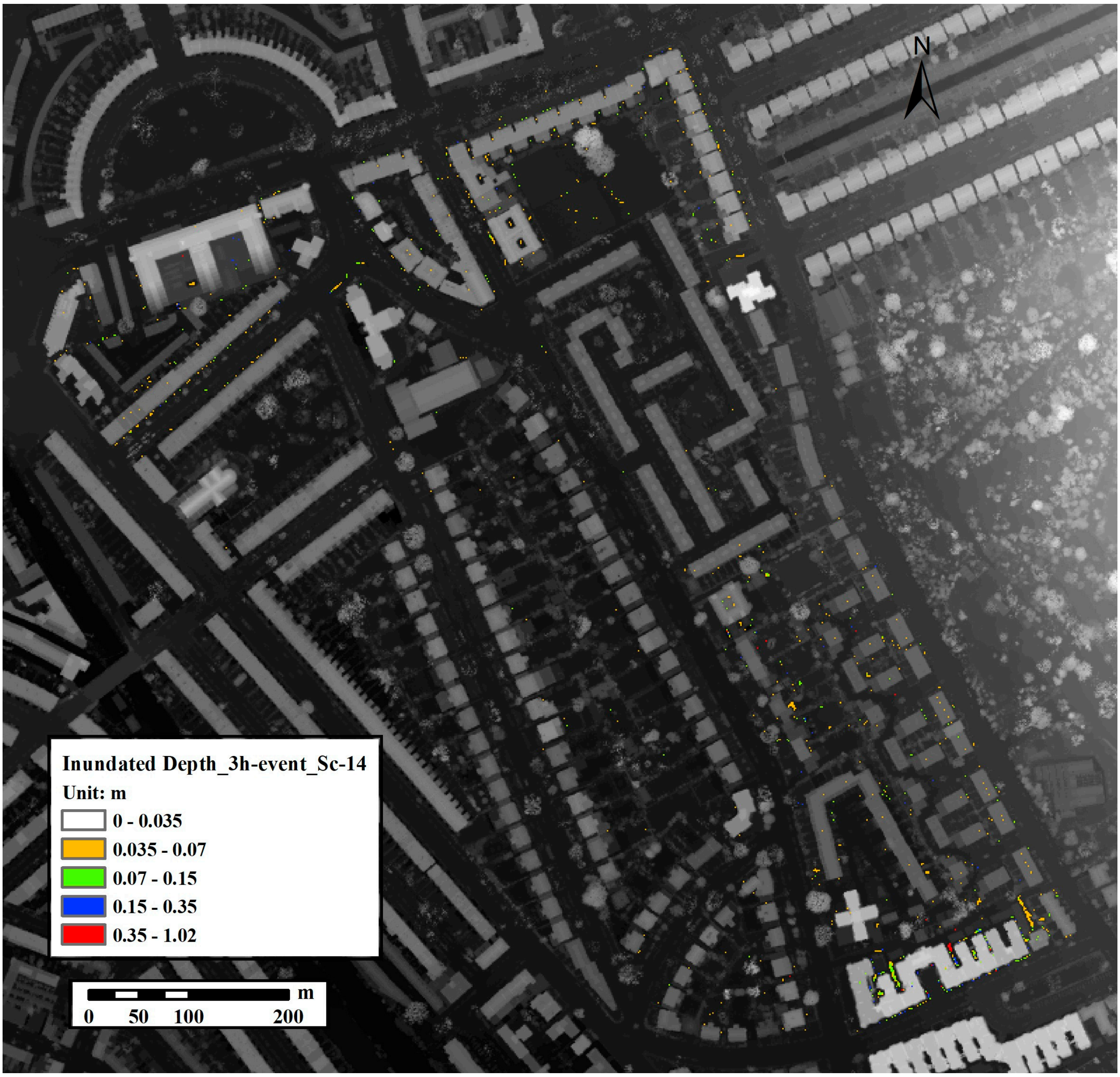

Fig. S71. Flood map of scenario 14 at the time of 4h (3-hour rainfall event)

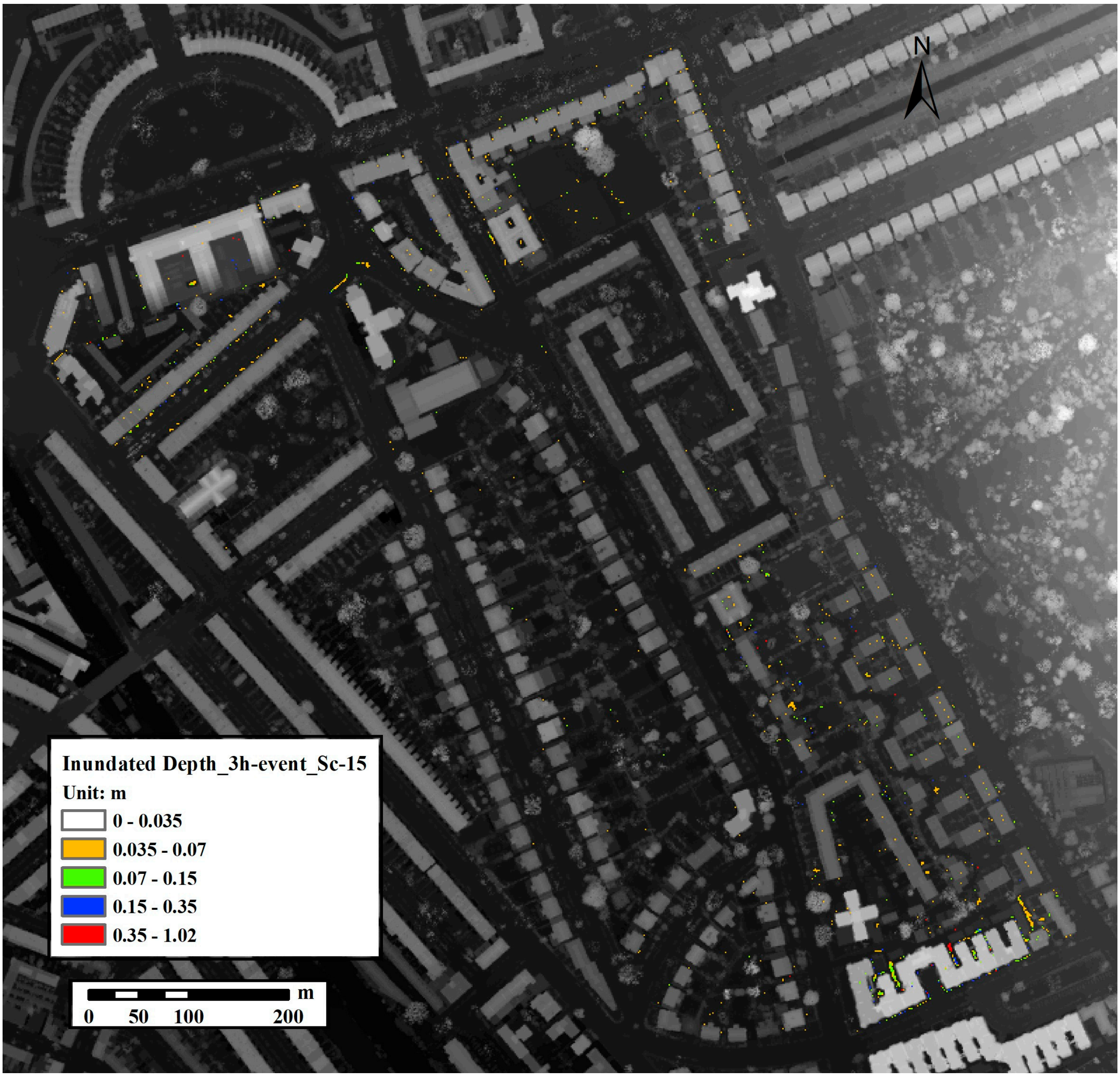

Fig. S72. Flood map of scenario 15 at the time of 4h (3-hour rainfall event)

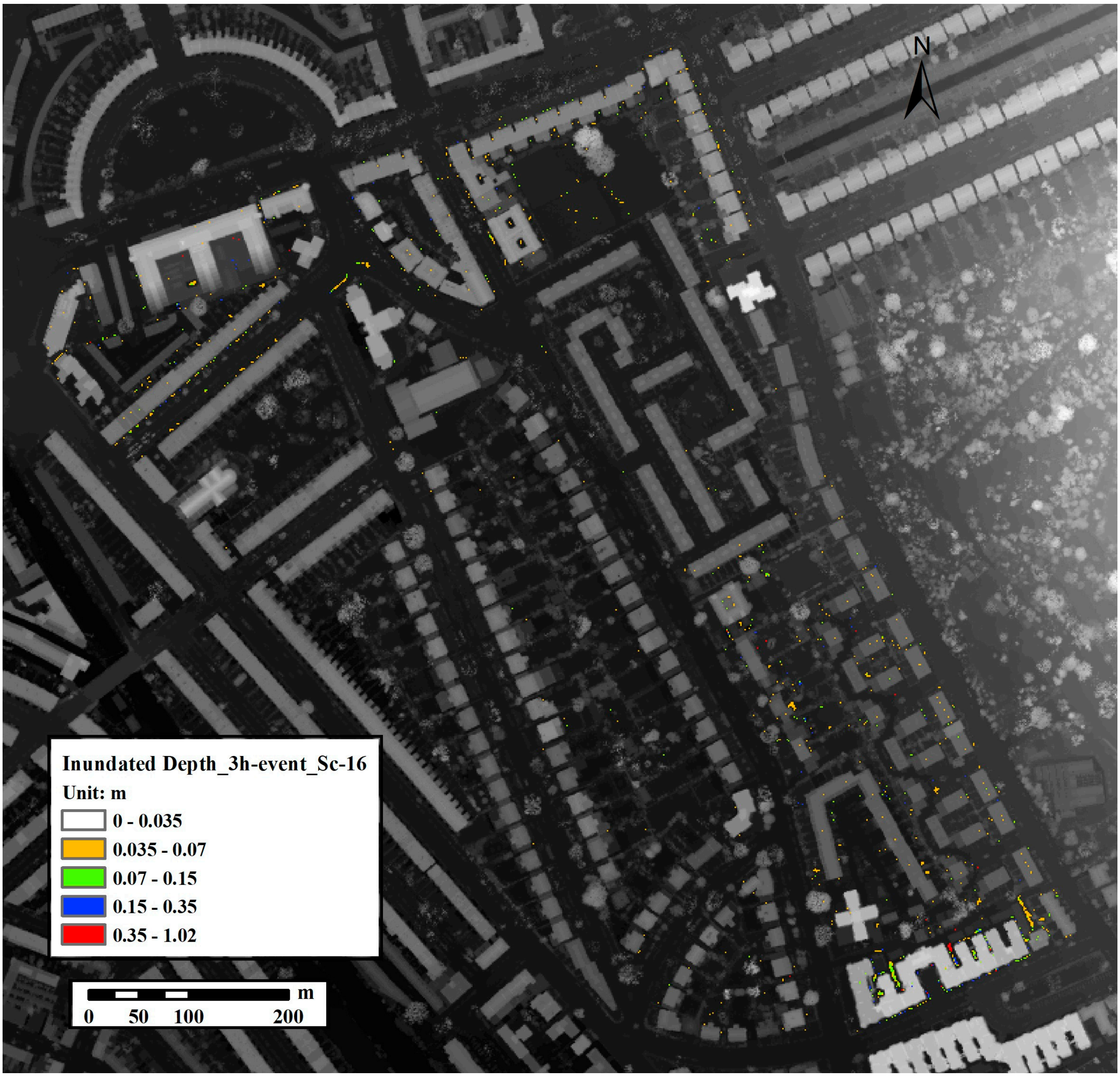

Fig. S73. Flood map of scenario 16 at the time of 4h (3-hour rainfall event)

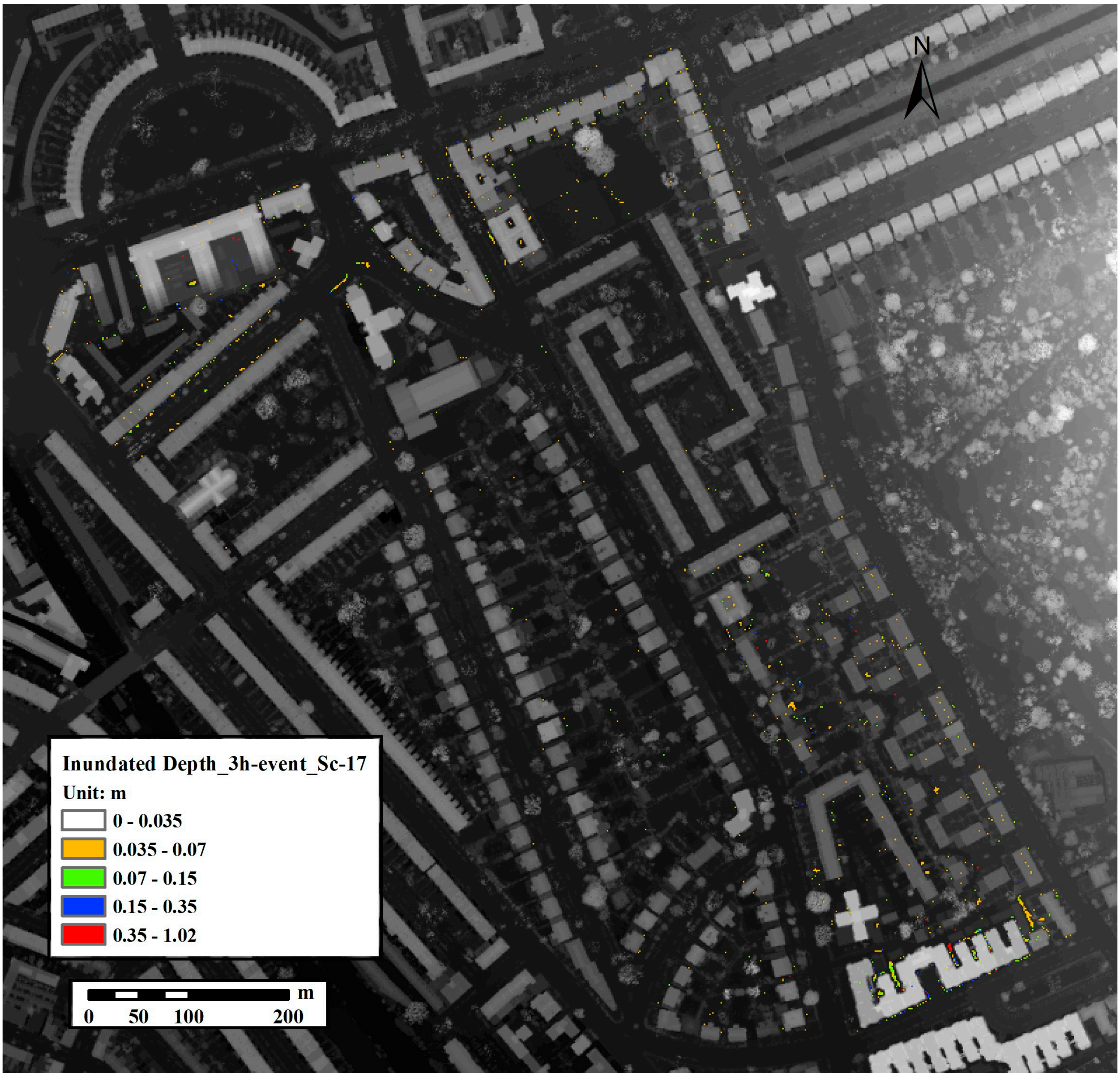

Fig. S74. Flood map of scenario 17 at the time of 4h (3-hour rainfall event)

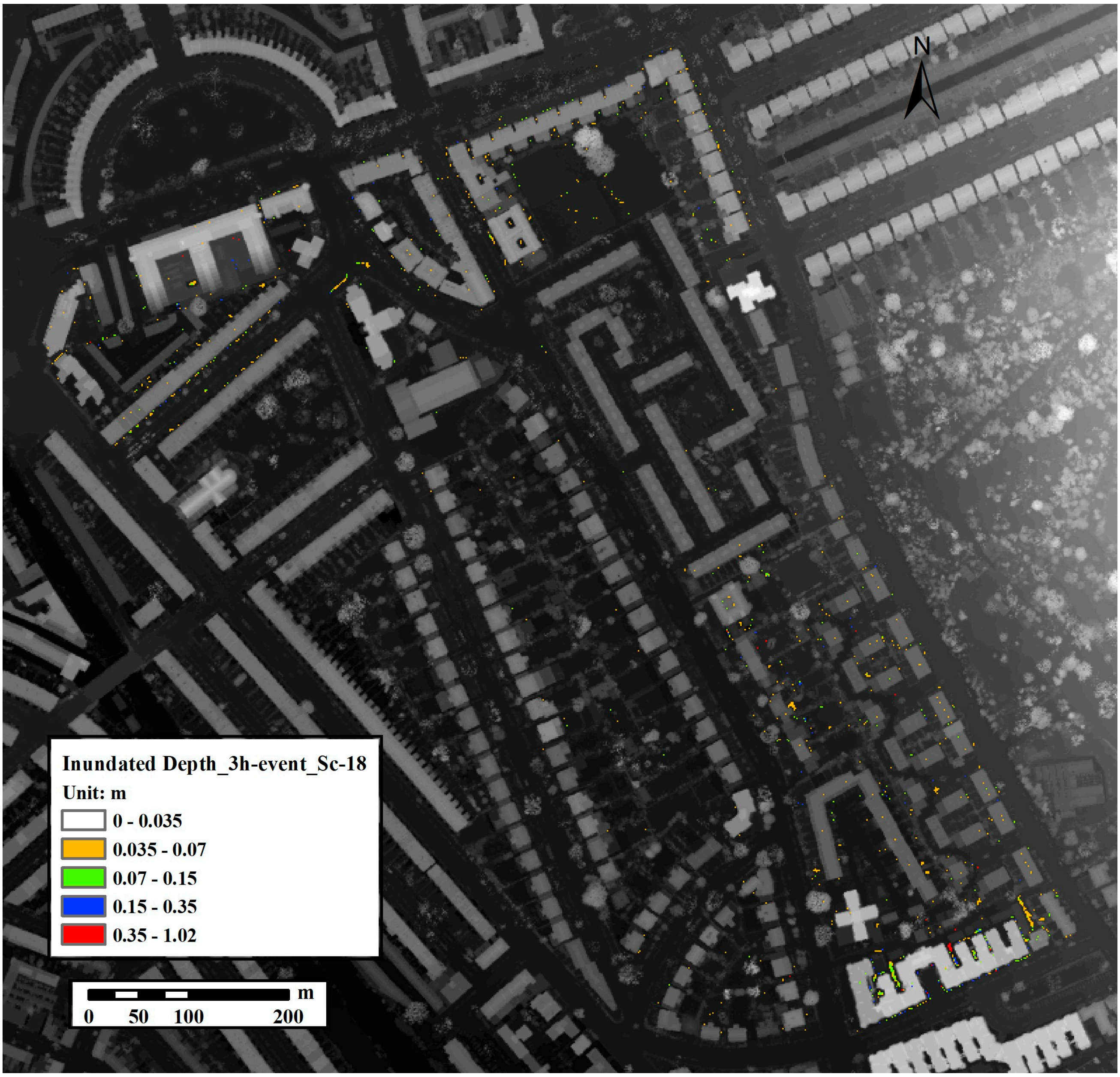

Fig. S75. Flood map of scenario 18 at the time of 4h (3-hour rainfall event)

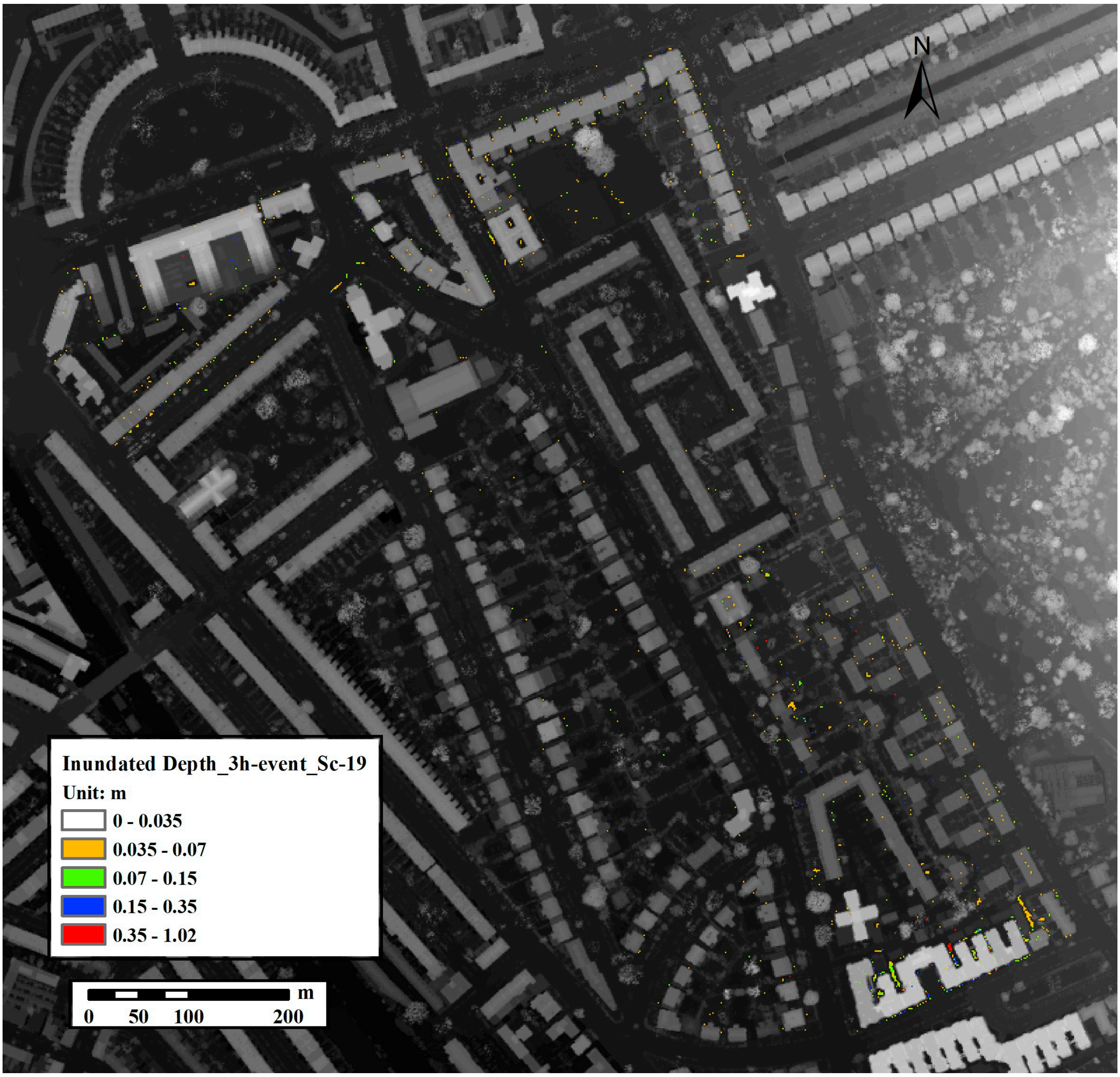

Fig. S76. Flood map of scenario 19 at the time of 4h (3-hour rainfall event)

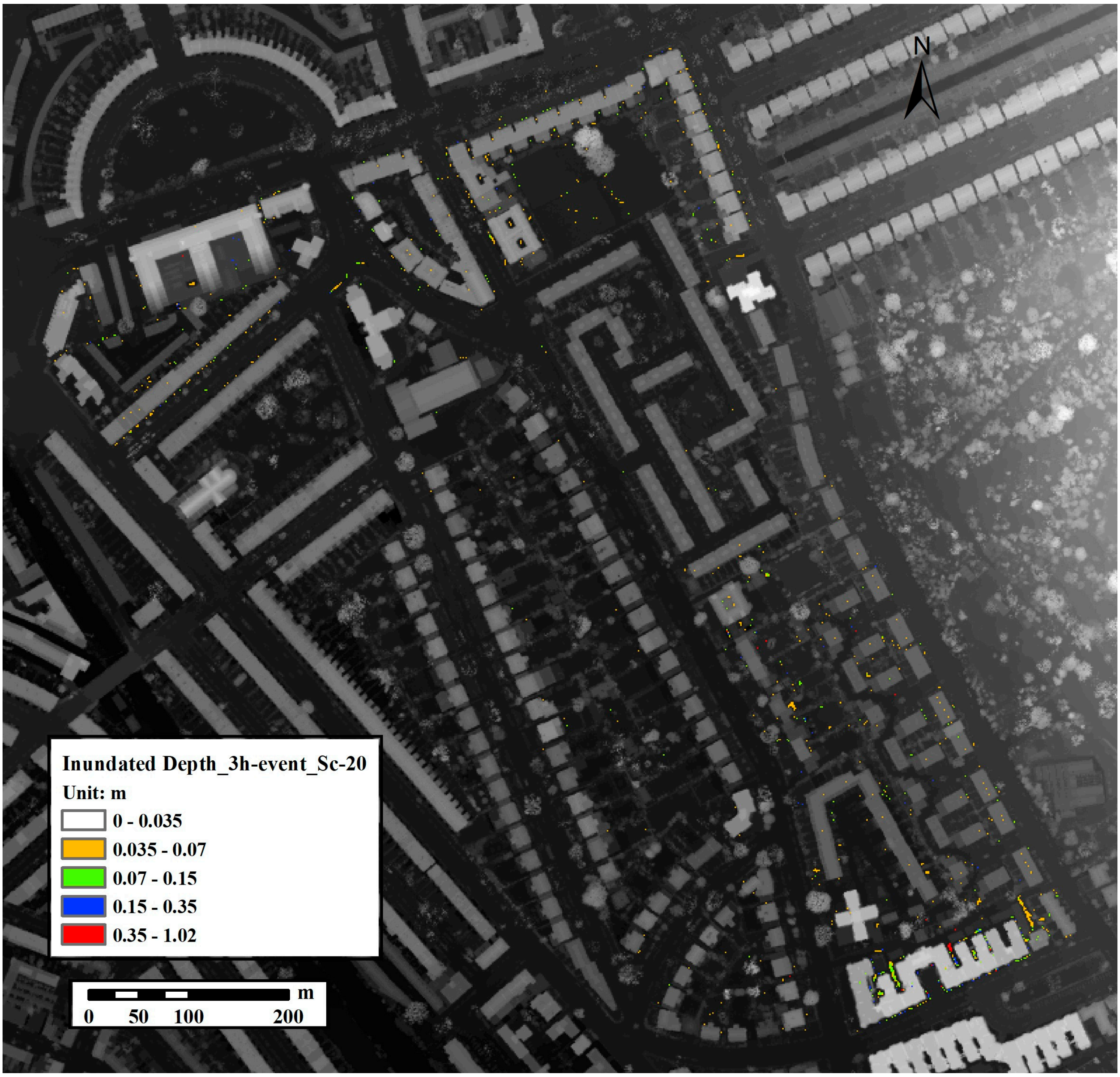

Fig. S77. Flood map of scenario 20 at the time of 4h (3-hour rainfall event)

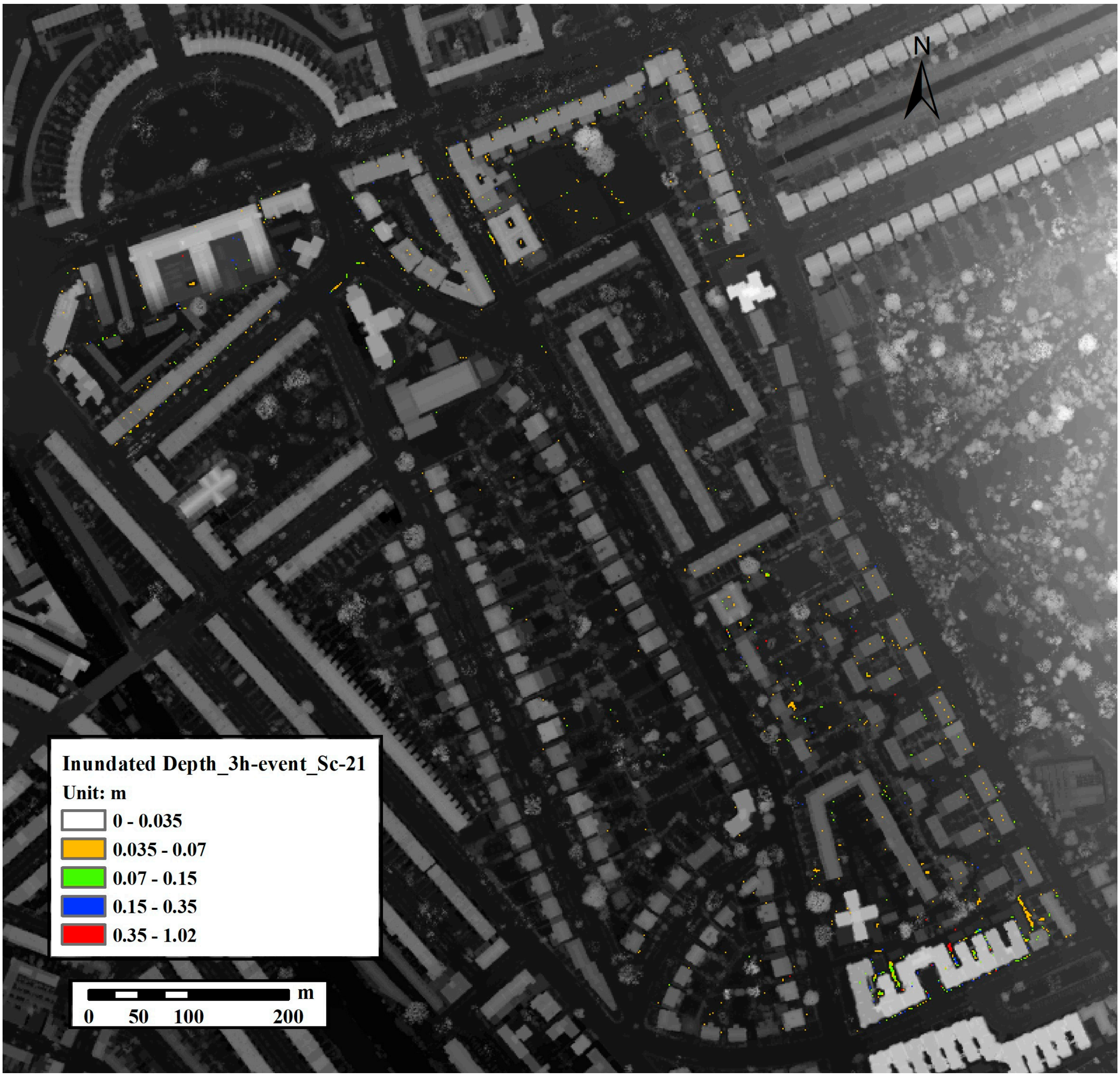

Fig. S78. Flood map of scenario 21 at the time of 4h (3-hour rainfall event)

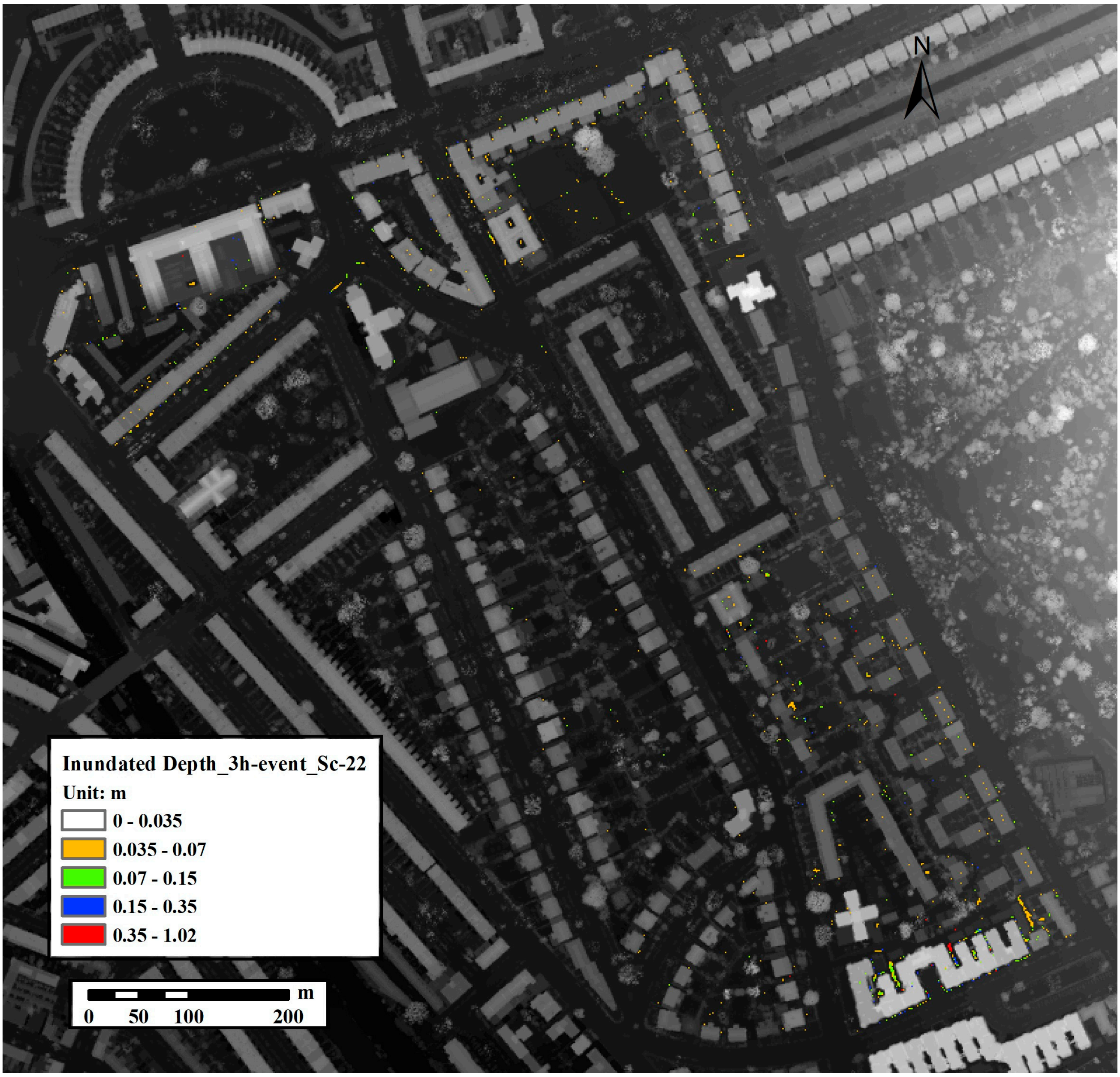

Fig. S79. Flood map of scenario 22 at the time of 4h (3-hour rainfall event)

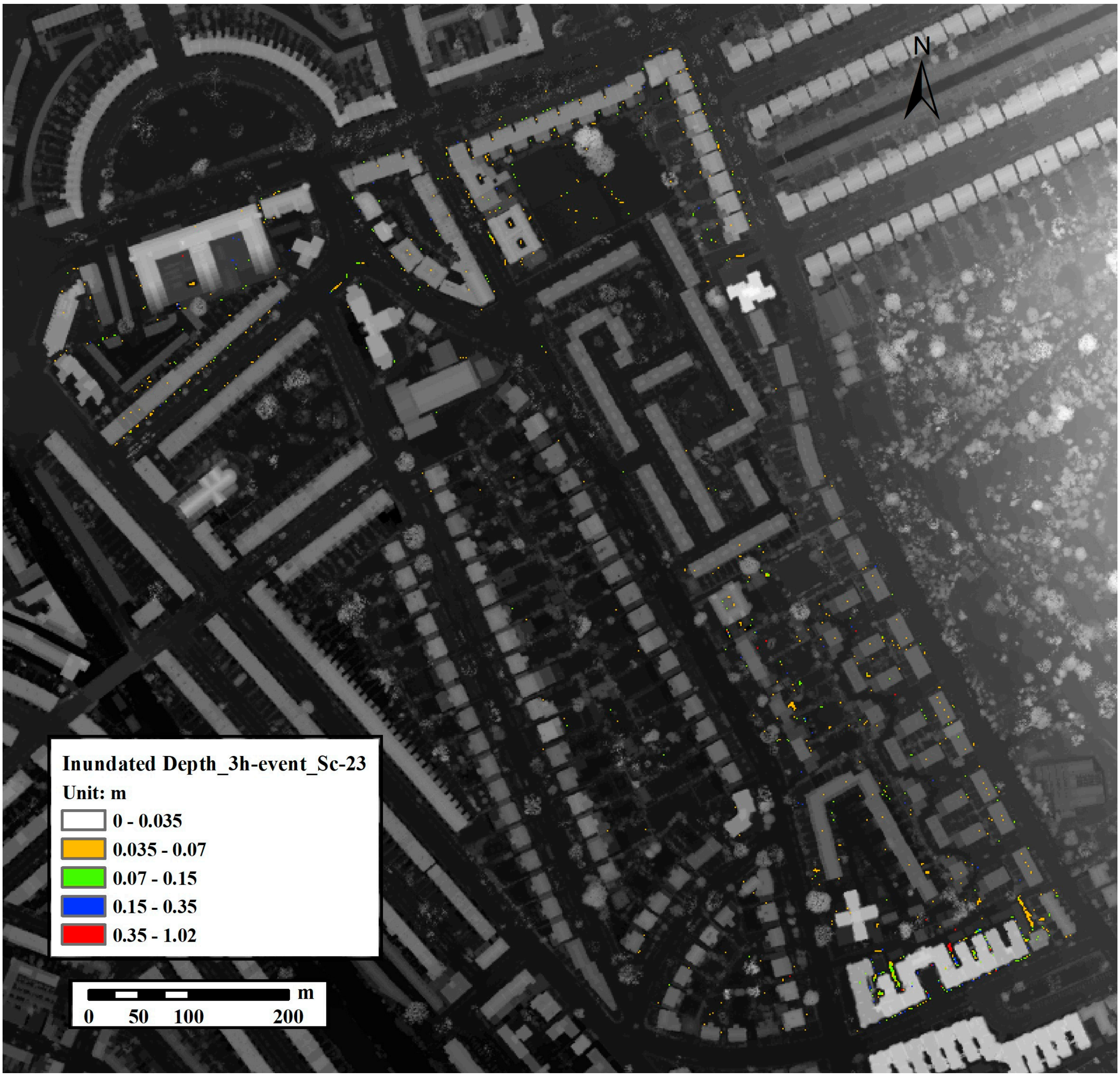

Fig. S80. Flood map of scenario 23 at the time of 4h (3-hour rainfall event)

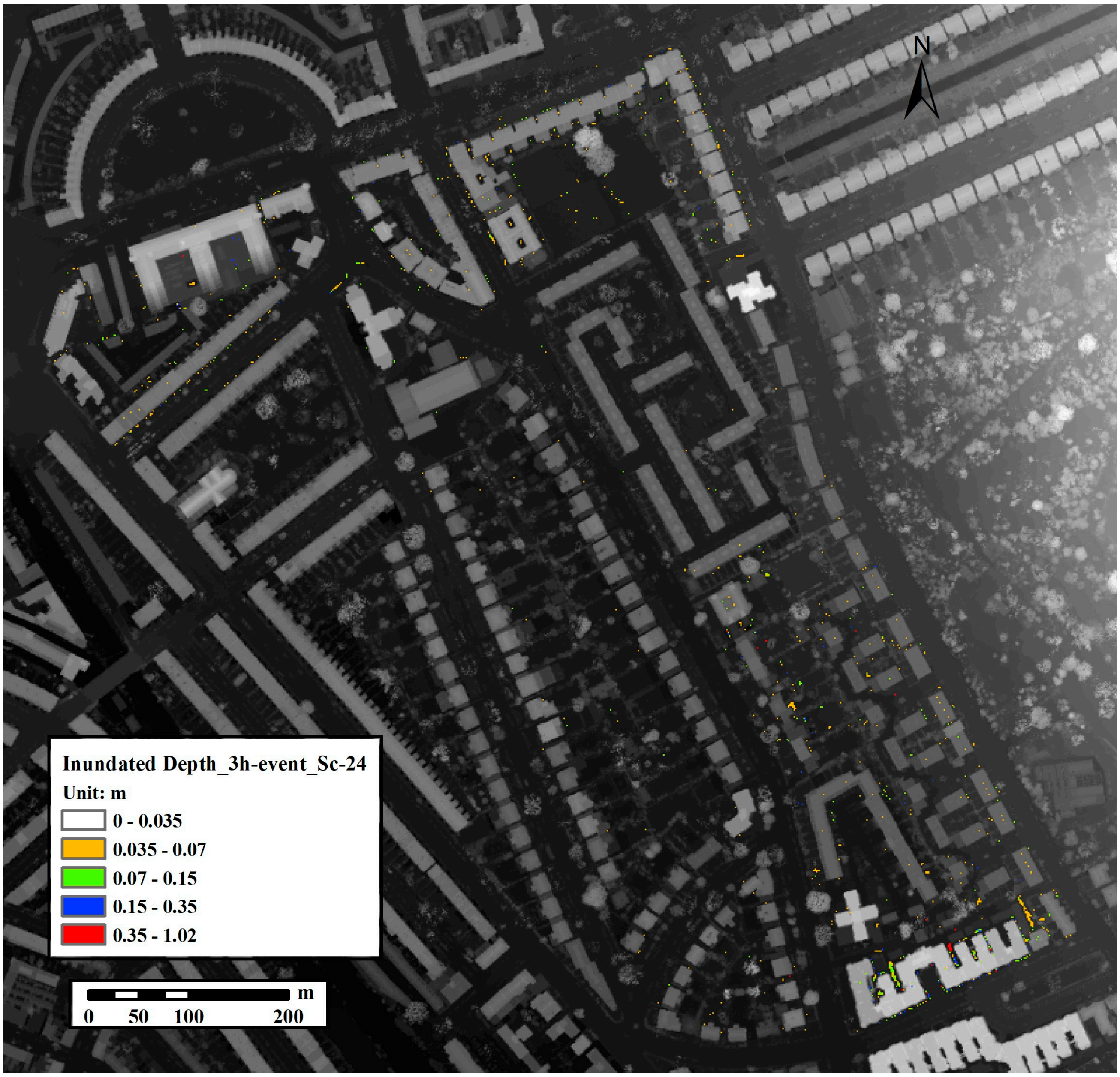

Fig. S81. Flood map of scenario 24 at the time of 4h (3-hour rainfall event)

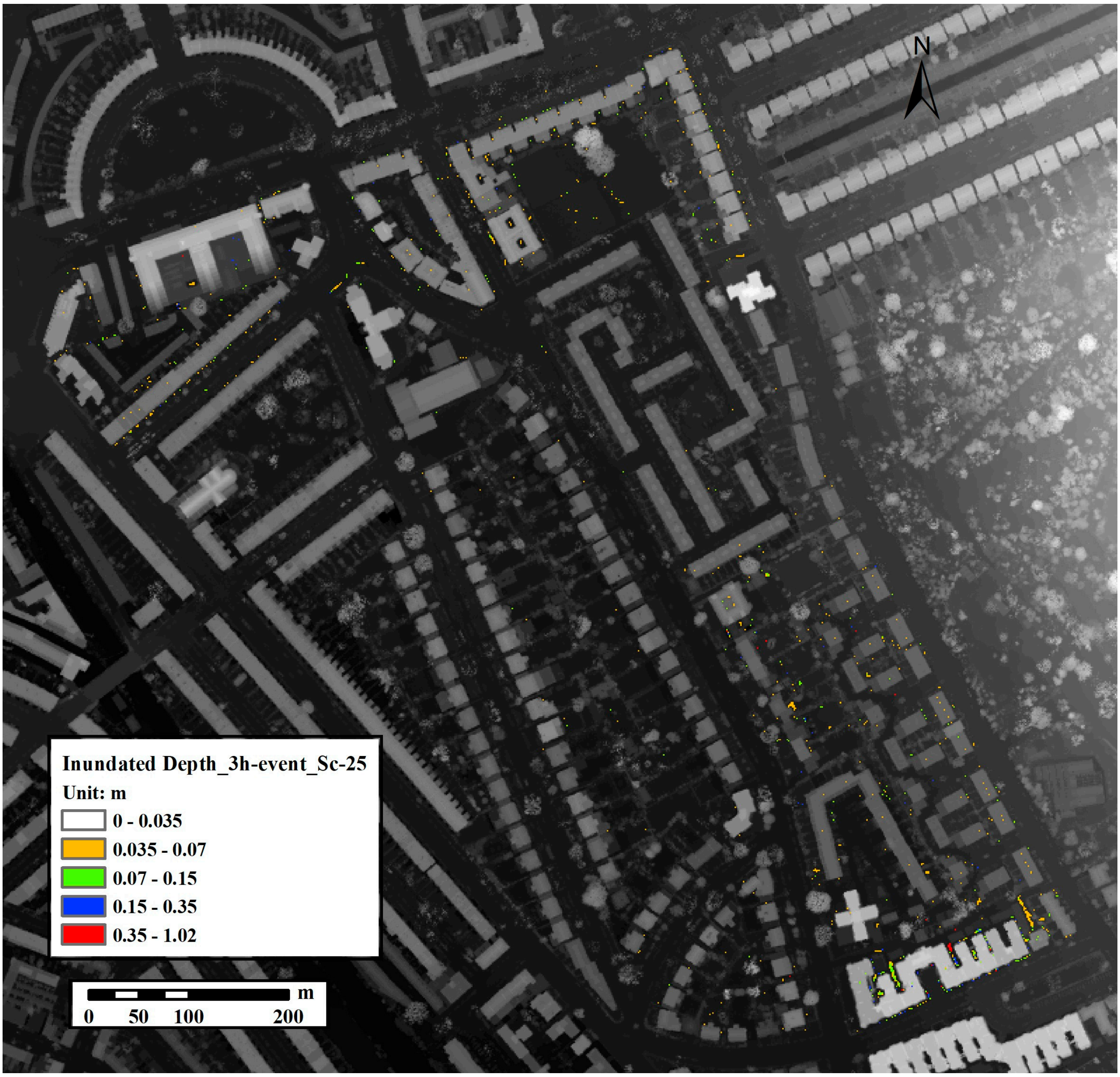

Fig. S82. Flood map of scenario 25 at the time of 4h (3-hour rainfall event)

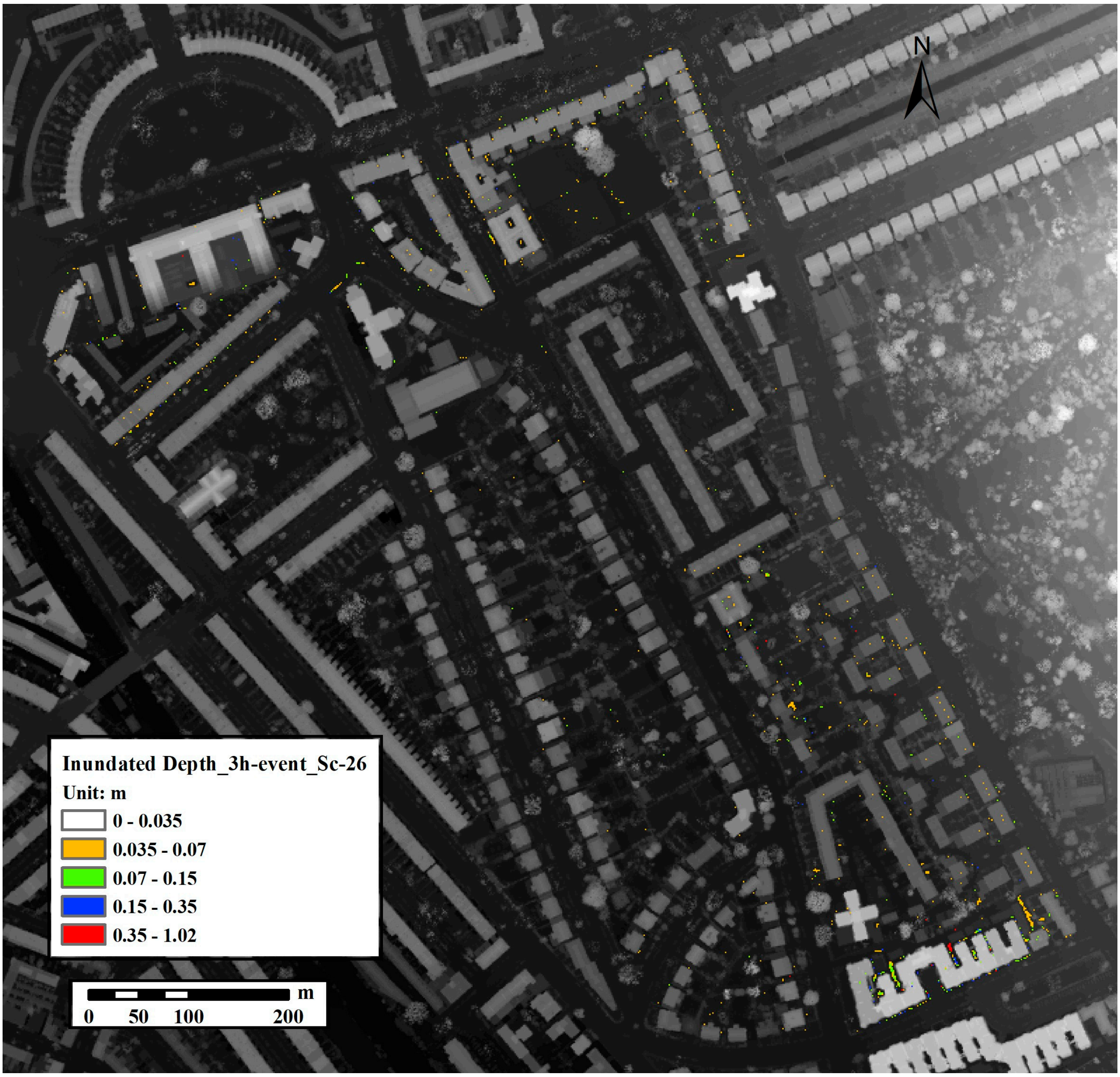

Fig. S83. Flood map of scenario 26 at the time of 4h (3-hour rainfall event)

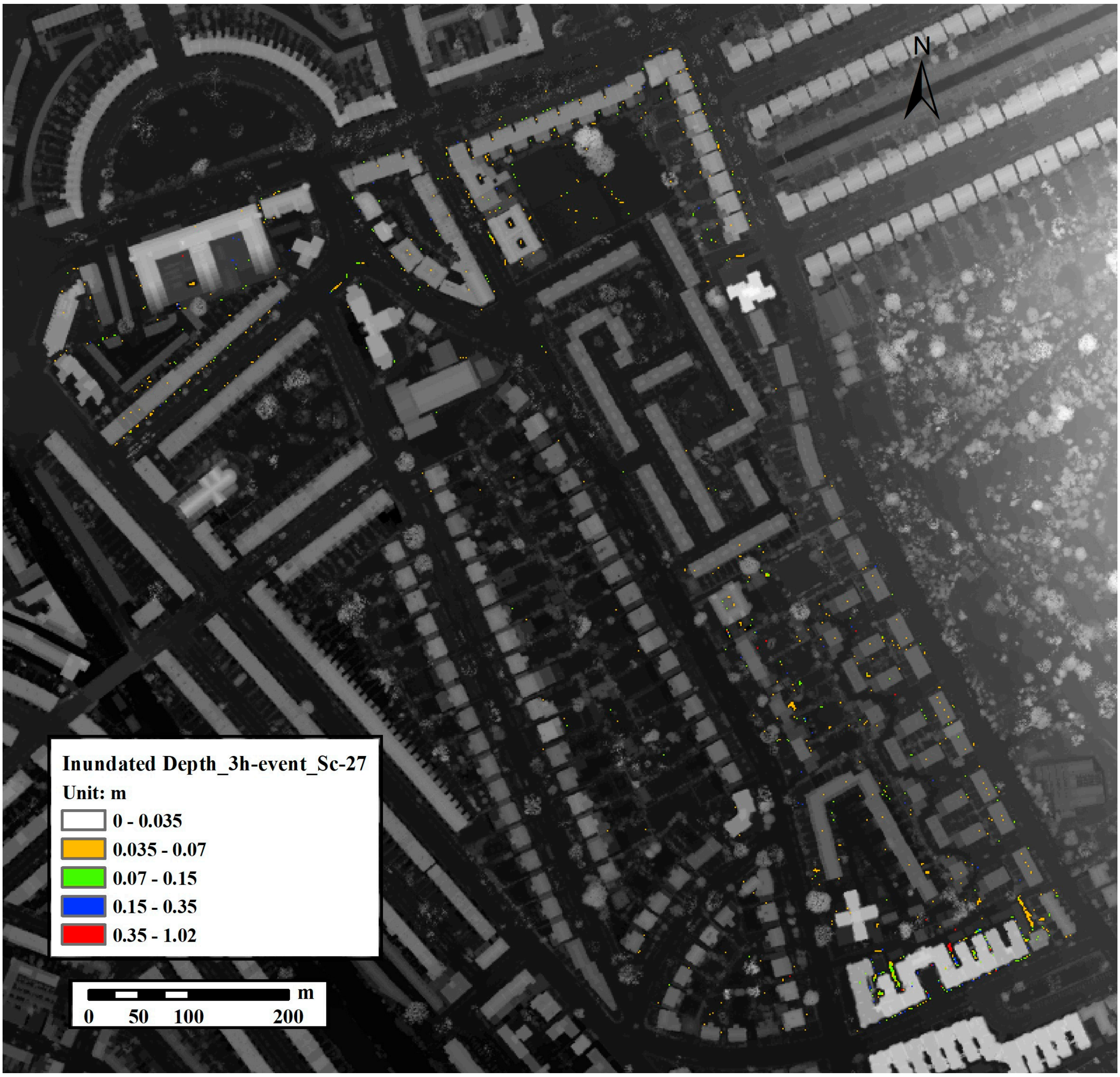

Fig. S84. Flood map of scenario 27 at the time of 4h (3-hour rainfall event)