



**HAL**  
open science

## A distributed modelling approach to assess the use of Blue and Green Infrastructures to fulfil stormwater management requirements

Pierre-Antoine Versini, N. Kotelnikova, A. Poulhes, I. Tchiguirinskaia, D.  
Schertzer, F. Leurent

### ► To cite this version:

Pierre-Antoine Versini, N. Kotelnikova, A. Poulhes, I. Tchiguirinskaia, D. Schertzer, et al.. A distributed modelling approach to assess the use of Blue and Green Infrastructures to fulfil stormwater management requirements. *Landscape and Urban Planning*, 2018, 173, pp.60-63. 10.1016/j.landurbplan.2018.02.001 . hal-02060156

**HAL Id: hal-02060156**

**<https://enpc.hal.science/hal-02060156v1>**

Submitted on 15 Mar 2019

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

and Urban Planning

Elsevier Editorial System(tm) for Landscape

Manuscript Draft

Manuscript Number: LAND-D-18-00056R1

Title: A distributed modelling approach to assess the use of Blue and Green Infrastructures to fulfil stormwater management requirements

Article Type: Research Note

Keywords: blue green infrastructures, stormwater management, distributed modelling

Corresponding Author: Dr. Pierre-Antoine Versini, Dr

Corresponding Author's Institution: Ecole des Ponts ParisTech

First Author: Pierre-Antoine Versini, Dr

Order of Authors: Pierre-Antoine Versini, Dr; Natalia Kotelnikova, Dr.; Alexis Poulhes, Dr.; Ioulia Tchiguirinskaia, Dr.; Daniel Schertzer, Prof.; Fabien Leurent, Prof.

Abstract: Blue and green infrastructures (B&GI) are nature-based solutions considered as particularly efficient to reduce the potential impact of new and existing developments with respect to stormwater issues. In order to assess their performances at some large scales compatible with urban projects, adapted distributed rainfall-runoff models are required. The latest advancements of the Multi-Hydro platform have made possible the representation of such B&GI. Applied in a virtual new urban development project located in the Paris region, Multi-Hydro has been used to simulate the impact of B&GI implementation, and their ability to fulfil regulation rules authorizing the connexion to the sewer network. The results show that a combination of several B&GI, if they are widely implemented, could represent an efficient tool to meet regulations at the parcel scale, as they can reduce runoff volume about 90%.

**A distributed modelling approach to assess the use of Blue and Green  
Infrastructures to fulfil stormwater management requirements**

P.-A. Versini<sup>1,\*</sup>, N. Kotelnikova<sup>2</sup>, A. Poulhes<sup>2</sup>, I. Tchiguirinskaia<sup>1</sup>, D. Schertzer<sup>1</sup>, F. Leurent<sup>2</sup>

<sup>1</sup> HMCo, Ecole des Ponts ParisTech, Champs-sur-Marne, France

<sup>2</sup> LVMT, Ecole des Ponts ParisTech, Champs-sur-Marne, France

\* Corresponding author: pierre-antoine.versini@enpc.fr

1           **A distributed modelling approach to assess the use of Blue and Green**  
2           **Infrastructures to fulfil stormwater management requirements**

3  
4

5 Blue and green infrastructures (B&GI) are nature-based solutions considered as  
6 particularly efficient to reduce the potential impact of new and existing developments  
7 with respect to stormwater issues. In order to assess their performance at some large  
8 scales compatible with urban projects, adapted distributed rainfall-runoff models are  
9 required. The latest advancements of the Multi-Hydro platform have made possible  
10 the representation of such B&GI. Applied in a virtual new urban development project  
11 located in the Paris region, Multi-Hydro has been used to simulate the impact of  
12 B&GI implementation, and their ability to fulfil regulation rules authorizing the  
13 connexion to the sewer network. The results show that a combination of several  
14 B&GI, if they are widely implemented, could represent an efficient tool to meet  
15 regulations at the parcel scale, as they can reduce runoff volume about 90%.

16

17 Key words: blue green infrastructures, stormwater management, distributed modelling

18  
19

20   **1 Introduction**

21

22 Blue and Green Infrastructures (B&GI), including green roof, bio-retention swale,  
23 porous pavement, harvesting tank, soakaway or pond for instance, can provide  
24 multiple benefits to urban areas affected by both climate change and urbanization  
25 effects: urban heat island reduction, biodiversity conservation, reduced buildings  
26 energy requirements,... Last but not least, they appear to be particularly efficient in  
27 stormwater management (Liao et al, 2017). By detention, infiltration and  
28 evapotranspiration processes, they can be used to control urban runoff at the local  
29 scale.

30

31 The hydrological performance and benefit of B&GI have been shown in numerous  
32 studies conducted at small scales: Kamali et al. (2017) for porous pavement,  
33 Chapman and Horner (2010) for bioretention system, or Stovin et al. (2012) for green  
34 roofs. Nevertheless, their performance and interaction at higher scales (urban project)

35 are still uncertain and insufficiently quantified. Modelling tools are required to  
36 consider B&GI configuration and optimize their performance, as most of the existing  
37 models are focused on one or very few assets such as green roofs (Versini et al.,  
38 2015). Few of them are technically able to combine dynamically several  
39 infrastructures, but usually in a semi-distributed approach that mixes several types of  
40 landcover (road, house, grass, park...), and implies some huge difficulties to adjust *a*  
41 *priori* the parameters without observed data. It is the case of the Storm Water  
42 Management Model, as shown in Lucas et al. (2015) or Palla and Gnecco (2015)  
43 among others. To properly assess B&GI performance on a large set of spatial scales, a  
44 hydrologic model characterized by a high spatial resolution is also required. Such a  
45 structure is necessary to consider heterogeneous surfaces, and the associated  
46 dynamics due to the layout of impervious and pervious areas.

47

48 Based on these considerations, the main objective of this research note is to assess the  
49 performance of B&GI in stormwater management at the urban project scale. A  
50 distributed modelling approach has been chosen to especially study the respective  
51 performance of a B&GI set, and their evolution regarding storm event return periods.

52

## 53 **2 Presentation of the case study: the “Echangeur” project**

54

55 The virtual urban project called “Echangeur” has been designed by a group of  
56 students during a specialized master training devoted to the “Ecodesign of Sustainable  
57 Cities”. Supported by the Academic Chair on the Eco-design of building sets and  
58 infrastructure established by ParisTech and the Vinci group (see Kotelnikova et al.,  
59 2016 for a detailed presentation), the main activity of this course is to design a  
60 sustainable neighborhood materialized by a layout plan. Located in the eastern  
61 suburbs of Greater Paris (Champs-sur-Marne, France) and covering an area of 10.66  
62 ha, the plan proposed by the students for the Echangeur project (Figure 1) hosts  
63 accommodation for 5900 inhabitants and activities with the creation of 1150 jobs.  
64 This plan must also fulfill stormwater management requirements concerning the  
65 connection to the stormwater network. Here the discharge at the parcel outlet has to  
66 be lower than a reference threshold of 10 l/s/ha for a rainy event characterized by a  
67 20-years return period. In the Paris region, this corresponds to a 30-minute rainfall  
68 event characterized by a 50 mm/h intensity.

69

70 Figure 1. Layout of the Echangeur catchment differentiating the different land use  
71 classes

72

73 Due to a lack of space, the construction of a large storage unit has not been  
74 considered. Several blue and green infrastructures have been planned to fulfil this  
75 stormwater regulation rule: (i) Green spaces (grass, forest and vegetable gardens), (ii)  
76 green roofs, (iii) green swales (swaled drainage course with sloped sides and filled  
77 with vegetation and riprap), (iv) small retention basins, (v) porous pavement.

78

### 79 **3 Materials and method**

80

#### 81 3-1 The Multi-Hydro model

82

83 The Multi-Hydro distributed rainfall-runoff model represents a well-adapted tool to  
84 assess hydrological impacts at the urban scale (Giangola-Murzyn, 2014, Ichiba et al,  
85 2017). For each time step, Multi-Hydro provides overland water depth (flooding) and  
86 infiltration maps, but also discharge values for each pipe and junction of the  
87 stormwater network. Multi-Hydro is currently being developed at the XXX to take  
88 into account the wide complexity of urban environments. The latest advancements  
89 have made possible the representation of several “resilience infrastructures” such as  
90 basins, barriers, and green roof (see Versini et al., 2016 for details). Based on these  
91 previous works, Multi-Hydro has been adapted to reproduce the hydrological  
92 behaviour of the mentioned B&GI planned in the Echangeur project.

93

94 Multi-Hydro has been implemented on this case study to simulate its hydrological  
95 response with a resolution of 5 m in space and 5 minutes in time. Based on the layout  
96 plan, the input data required by the model (map of topography, landuse and  
97 stormwater network) were produced by using adapted GIS tools.

98

#### 99 3-2 Land use scenarios

100

101 In order to study the relative contribution of each implemented B&GI, different land  
102 use scenarios have been established: (0) there is no blue or green infrastructure, but

103 only impervious surfaces such as roads, buildings and pavements, (1) Green spaces  
104 are implemented, (2) Every building roof is covered with an extensive green roof, (3)  
105 Green swales are implemented, (4) Impervious pavements are replaced with porous  
106 ones on the pedestrian area, (5) Most of the stormwater network outfalls are  
107 connected to two small retention basins, (6) All of the B&GI mentioned above are  
108 implemented.

109

110 3-3 Rainfall scenarios

111

112 To quantify the relative performance of B&GI regarding stormwater management  
113 issue, several rainfall scenarios have been provided. These are synthetic hyetographs  
114 characterized by a homogenous precipitation and based on the specific Intensity-  
115 Duration-Frequency relationship (established in a station located 20 km away from  
116 the studied area by Météo-France). They were computed for a 30-minute duration  
117 (close to the watershed concentration time) and several return periods (see Table 1).

118

119 Table 1. Rainfall intensity (expressed in mm/h) for the 8 considered return periods

120

121 3-4 Work plan

122

123 Multi-Hydro was applied on every land use and rainfall scenario (7x8 simulations).  
124 Some of the resulting hydrographs are illustrated in Figure 2 and analysed in the  
125 following. Note that two indicators were used to assess B&GI performance: runoff  
126 volume ( $\Delta V$ ) and peak discharge ( $\Delta Qp$ ) reductions:

127 
$$\Delta Qp(\%) = \frac{(Qp_0 - Qp_i)}{Qp_0} \cdot 100 \quad (\text{Eq. 2})$$

128

129 
$$\Delta V(\%) = \frac{(V_0 - V_i)}{V_0} \cdot 100 \quad (\text{Eq. 3})$$

130 Where  $Qp_0$  and  $V_0$  refer to peak discharge and runoff volume computed for the  
131 impervious situation, whereas  $Qp_i$  and  $V_i$  correspond to those computed for the  
132 different B&GI scenarios.

133

#### 134 **4 Presentation of the results**

135 For the impervious situation, most of the rainfall volume is transferred to the basin  
136 outfalls. Only initial losses and water stored in local depression can be deduced.

137 Regarding 30-minute duration events, peak discharge reaches 200 l/s to 1200 l/s. It is  
138 worth noting that regulation threshold is exceeded whatever the return period of the  
139 considered storm event.

140

141 When 11.6% of the total area is covered by green spaces (Scenario 1), runoff volume  
142 and peak discharge decrease by approximately 10-15% for the more frequent events,  
143 and less than 10% for the strongest ones. In these cases, infiltration capacity of green  
144 spaces is reduced, and some water is finally drained to the stormwater network

145

146 The green roof implantation proposed in Scenario 2 -representing 42.3% of the  
147 watershed area- induces both runoff volume and peak discharge reduction starting  
148 from 15% to 25% for the more frequent storm events, and dropping to about 5% for  
149 the heaviest ones. Green roofs appear to be particularly efficient at the beginning of  
150 the storm, when they can temporarily store water in the substrate.

151

152 In Scenario 3, Green swales represent a small part of the studied basin (5.5%), but  
153 they drain water from surrounding elements (almost 30% of the total area). It is  
154 illustrated by some runoff volume and peak discharge reductions that vary from 30%  
155 for the 1-month event to 17% for the 20-year one.

156

157 As porous pavements represent 31.5% of the whole area, their implementation in  
158 Scenario 4, characterized by a high storage capacity, significantly influences the  
159 hydrological response of the catchment. Both runoff volume and peak discharge  
160 decrease about 30-40% depending on the considered rainfall event.

161

162 Retention basins drawn up in Scenario 5 represent the most effective infrastructure in  
163 terms of runoff reduction as they drain two thirds of the catchment area. Both runoff  
164 volume and peak discharge decrease of about 70% for the more common storm  
165 events. For the highest events, the total storage capacity (1300 m<sup>3</sup>) is reached. From  
166 that time, the exceeded water is routed to the stormwater network and produces a  
167 “step” in the catchment response.

168

169 The implementation of all of the B&GIs on the Echnageur project (Scenario 6) is  
170 obviously the most effective configuration. Both peak discharge and runoff volumes



171 are reduced by about 90% on the wide range of return periods, and the regulation rule  
172 of 10 l/s/ha is almost always met (except for the two main events).

173

174 Figure 2. Presentation of the simulated hydrographs for different rainfall events and  
175 B&GI scenarios. Orange horizontal solid line corresponds to the 10 l/s/ha regulation.

176

## 177 **5 Conclusions and perspectives**

178

179 A combination of B&GI appears to be the best solution to significantly reduce the  
180 quantity of water flowing into the sewage network during storm events, and to fulfil  
181 regulation rules established by local stormwater managers. The distributed structure  
182 of Multi-Hydro and the possibility to reproduce a large set of B&GI allow the  
183 realization of such detailed and dynamic impact studies. As Multi-Hydro is still in  
184 development, additional B&GI could be added in the future, and among these,  
185 different configurations could be tested (ie. several green roofs differentiated by their  
186 substrate porosity or thickness).

187

188 The presented results must be taken with caution, as they depend on the catchment  
189 configuration, especially on the combination of impervious and pervious surfaces, but  
190 also on its geometry and on the sewage network arrangement. Moreover, it should  
191 also be noticed that initial conditions have not been considered in this study. Every  
192 B&GI was assumed to be empty / unsaturated at the beginning of every rainfall event.  
193 Future versions of Multi-Hydro should take into account evapotranspiration processes  
194 and detention basins draining during dry periods to better estimate the initial state of  
195 the system. The succession of several rainfall events should also be possible to study  
196 B&GI performance in more realistic conditions, as it is usually the case for rainwater  
197 harvesting tank or detention basin sizing.

198

## 199 **Acknowledgments**

200

## 201 **References**

202 Chapman, C., & Horner, R.R. (2010). Performance assessment of a street- drainage  
203 bioretention system. *Water Environ. Res.*, 82 (2), 109–119

204 Giangola-Murzyn, A. (2014). Modélisation et paramétrisation hydrologique de la  
205 ville, résilience aux inondations, PhD thesis, Université Paris-Est, 260 pp.

206 Ichiba, A., Gires, A., Tchiguirinskaia, I., Schertzer, D., Bompard, P., & Ten Veldhuis,  
207 M.-C. (2017). Scale effect challenges in urban hydrology highlighted with a  
208 distributed hydrological model. *Hydrol. Earth Syst. Sci. Discuss.*,  
209 <https://doi.org/10.5194/hess-2017-286>

210 Kamali, M., Delkash, M., & Tajrishy, M. (2017). Evaluation of permeable pavement  
211 responses to urban surface runoff, *Journal of Environmental Management*,  
212 187, 43-53

213 Kotelnikova, N., De Bartoli, A., Féraïlle, A., & Leurent, F. (2016). Integrating Urban  
214 Ecodesign in French engineering curricula: an example at École des Ponts  
215 ParisTech. *International Conference on Sustainable Built Environment*,  
216 Hamburg, Germany

217 Liao, KH., Deng, S., Tan, P.Y. (2017). Blue-Green Infrastructure: New Frontier for  
218 Sustainable Urban Stormwater Management. In: Tan P., Jim C. (eds) *Greening  
219 Cities. Advances in 21st Century Human Settlements*. Springer, Singapore

220 Lucas, W.C., & Sample, D.J. (2015). Reducing combined sewer overflows by using  
221 outlet controls for Green Stormwater Infrastructure: case study in Richmond,  
222 Virginia. *Journal of Hydrology*, 520, 473–488

223 Palla, A., & Gnecco, I. (2015). Hydrologic modeling of Low Impact Development  
224 systems at the urban catchment scale, *Journal of Hydrology*, 528, 361-368

225 Stovin, V., Vesuviano, G. & Kasmin, H. (2012). The hydrological performance of a  
226 green roof test bed under UK climatic conditions. *Journal of Hydrology*, 414-  
227 415, 148-161.

228 Versini, P.A., Gires, A., Tchiguirinskaia, I., & Schertzer, D. (2016). Toward an  
229 operational tool to simulate green roof hydrological impact at the basin scale:  
230 a new version of the distributed rainfall-runoff model Multi-Hydro. *Water  
231 Science and Technology*, 74(8), 1845-1854.

232 Versini, P.A., Jouve, P., Ramier, D., Berthier, E. & de Gouvello, B. (2015). Use of  
233 green roofs to solve storm water issues at the basin scale - Study in the Hauts-  
234 de-Seine county (France). *Urban Water Journal*.  
235 <http://dx.doi.org/10.1080/1573062X.2014.993993>

236

**List of Tables**

237

238 Table 1. Rainfall intensity (expressed in mm/h) for the 8 considered return periods

239

240

241

242

243

244

	1 month	3 months	6 months	1 year	2 years	5 years	10 years	20 years
D=30min	8.0	14.4	19.7	25.9	31.4	42.0	50.1	58.2

245

246

247

Figure 1  
[Click here to download high resolution image](#)

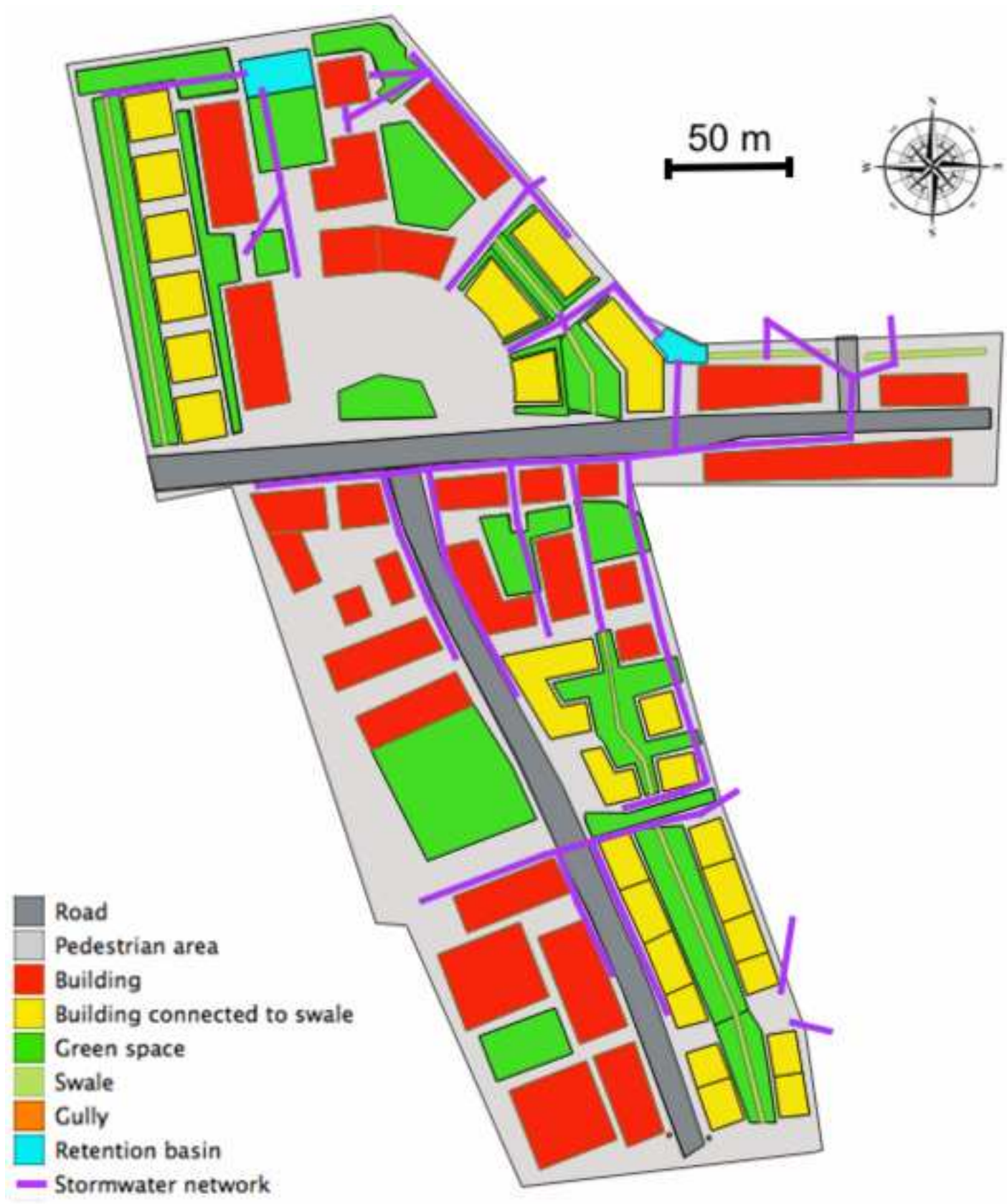


Figure 2  
[Click here to download high resolution image](#)

