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Impact of blue/green and grey infrastructure interventions on natural capital in urban development

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ABSTRACT

Natural capital can describe the multiple benefits people get from the natural environment. Both global and national trends show that natural capital has been declining overtime due to urbanisation and natural resource depletion. While urban intensification adversely influences natural capital, it is recognised that blue/green infrastructure systems driven by the need to manage stormwater (e.g. rain gardens, swales, ponds etc.) can mitigate such impacts. To capture this potential there is a need to mainstream natural capital assessments at the relevant scales to inform planning decisions and outcomes. The aim of this study is to investigate how future intensification will affect natural capital in a residential area of the London Borough of Sutton. The existing drainage network has exceeded its capacity and recent extreme rainfall events have led to increased flooding incidents. The local authority intends to integrate blue/green infrastructure with the existing grey infrastructure to promote sustainable growth. In this context, this study makes use of the Natural Capital Planning Tool (NCPT) and a GIS-based analysis to inform the impact of proposed developments on natural capital. Hydrodynamic modelling shows that blue/green interventions mitigate flood risk within the intensification zone and beyond. Different natural capital indicators, such as flood risk regulation, are assessed in different spatiotemporal scales and this poses a challenge in producing a coherent natural capital accounting score.

Keywords: natural capital, blue/green infrastructure, ecosystem services, multiple benefits, environmental assessments, urban planning.

INTRODUCTION

The world is becoming increasingly urbanised and according to the United Nations, 2.5 billion people will be added to the world's urban population by 2050 (United Nations, 2017). Urban intensification, exacerbated in many places by climate change, will increase existing flood risk (Ahmed et al., 2018; Akter et al., 2018; Zhou et al., 2019).

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Blue-green infrastructure, also known as nature based solutions, is being promoted as a sustainable approach to mitigate and/or adapt to flood risk (Depietri and McPhearson, 2017; Emilsson and Ode Sang, 2017). At the same time, it delivers a multitude of other socio-environmental benefits (Morgan and Fenner, 2017). Therefore, the adoption of such measures in the planning policies and design and construction codes has a potential to positively transform new urban districts or urban retrofit environments (Ellis et al., 2002; Pitidis et al., 2018).

Natural capital and ecosystem services concepts are a popular way of describing the multiple benefits people get from the natural environment. The publication of the Millennium Assessment in 2005 have, along with national publications such the UK National Ecosystem Assessment (DEFRA et al., 2011), raised the profile of the importance and study of these concepts. Natural capital refers to the stock of natural features/assets - e.g. freshwater, land, soil, minerals, air, seas, habitats, biodiversity and processes which together provide the foundation for the flows of ecosystem services (Guerry et al., 2015; Natural Capital Committee, 2015; Rouquette, 2016). Ecosystem services are the flows of benefits such as food production, flood regulation, climate regulation, carbon sequestration and recreational opportunities which people gain from natural ecosystems (Costanza et al., 2017).

Both global and national trends show that natural capital has been on the decline due to human influenced land use changes such as urbanisation and natural resource depletion (Holt et al., 2015; Natural Capital Committee, 2015). Understanding of these concepts has led to an interest in the development of suitable metrics, models, datasets and tools for measurement of natural capital as well as assessing how it is changing overtime. The Natural Capital Committee suggests the concept of natural capital be applied in core environmental contexts such as urban settings. Urban expansion/intensification impacts on natural capital and thus reduces the multiple benefits available to the urban population. However, it is increasingly recognised that blue/green infrastructure systems (e.g. rain gardens, swales, ponds etc.) can at least limit these impacts (Hansen and Pauleit, 2014).

While ecosystem services knowledge is already in use in urban planning, especially with respect to the multiple benefits achievable from blue/green infrastructure systems (Meerow and Newell, 2017; O'Donnell et al., 2017), there is still need for natural capital assessments at relevant scales to inform planning decisions and outcomes (Cortinovis and Geneletti, 2018). Furthermore, the multifunctionality of blue/green infrastructure systems beyond addressing just one main issue such as urban flooding - in most cases, has not been adequately explored and accounted for yet blue/green infrastructure systems are often promoted on their multifunctionality potential compared to grey infrastructure (Hansen and Pauleit, 2014). The multifunctionality of green infrastructure is mostly traded-off for locational/technical/physical factors and this in turn influences the multiple benefit categories among the urban communities. While the quality and quantity of green infrastructure is important, the Natural Capital Committee, 2015 also argues that its distribution and equity is of equal importance as it is usually the poor who lack access to good quality green infrastructure and associated multiple benefits.

The aim of this research is to investigate how different blue/green infrastructure investment pathways and future land use change scenarios affect the natural capital in the London Borough of Sutton.

METHODOLOGY

Study area

This study focuses on the area of Carshalton which is part of the London Borough of Sutton (LBS). The Borough is located in the south-western part of Greater London and covers an area of about 44 km^2. It contains mostly medium density residential areas. The Borough contributes to the catchments of the River Wandle and Beverley Brook which flow northwards towards the Thames River. The case study area has significantly expanded overtime, with plans to further introduce more housing units in the next three decades. The Council is currently developing a plan for approximately 3,000 new homes to provide housing to 10,000 new residents. As a result of this growth, the existing drainage network has exceeded its capacity and recent extreme rainfall events have led to increased flooding incidents. Future intensification is expected to increase flood risk. To address these challenges, the local authority intends to integrate blue/green infrastructure with existing grey infrastructure to reduce the flood risk. One of the drivers for the planning authority is the delivery of a "natural capital uplift". The council is also considering the development of SuDS on Streets (as a policy of Transport for London (TFL)). It is also interested in improving air quality, as parts of Sutton comprise Air Quality Management Areas (AQMA).

Development options

As shown in Figure 1, this work focuses on a specific 30-hectare potential intensification area. Current land use includes residences, urban allotments and open green space. An estimated 200 to 300 homes will be delivered in approximately 30% of the land available under a medium density development policy. This allows for public space to be co-delivered as well as new roads serving the area. The two main imaginary development approaches are tested and evaluated in this work, namely “grey approach” and a “blue green approach”. For the latter, green roofs, rainwater harvesting, raingardens and street swales are examined in separation or combined. The analysis uses the Natural Capital Planning Tool (Holzinger et al., 2018) and the hydrodynamic modelling tool, CityCat (Glenis et al., 2018).

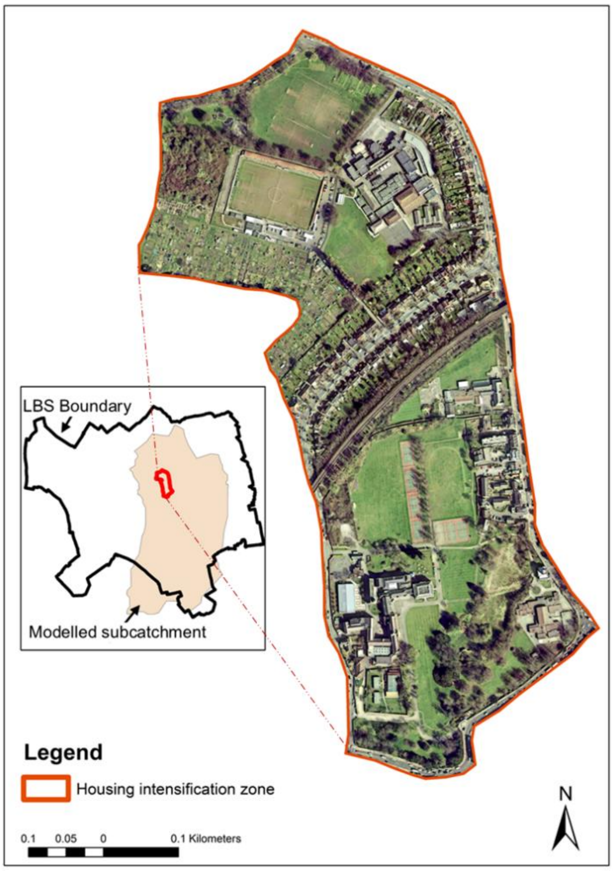


Figure 1. Current plan view of potential intensification area in Carshalton, London Borough of Sutton. The hydrological sub-catchment in which the intensification area lies is shown.

Natural Capital Planning Tool

In this study, the Natural Capital Planning Tool (Holzinger et al., 2018) was used to assess the likely impact of the proposed housing developments and different blue/green infrastructure interventions on natural capital over a 25 year timescale post development. All calculations are based on introducing a land-use change. Land use options are based on the Joint Nature Conservation Committee (phase 1) habitat survey and classification framework (DEFRA (JNCC), 2010). The proposed housing units will replace some of the existing green areas (mostly urban farm allotments) within the housing intensification zone identified by the local authority. The NCPT calculates the development impact score for 10 selected ecosystem services (multiple benefits), indicating the direction (positive or negative) and magnitude (calculated impact score) on each assessed ecosystem service and an overall development impact score for all ecosystem services combined. To do this, the assessor enters a range of indicator data such as population density, soil drainage class, size of green space sites and spatial land use information for the pre- and post-development state of the site under assessment. Some of this information is freely available online (intensification area, existing land use, soil type, flood risk zoning, demographics, air quality) but in some cases a GIS analysis is required to acquire this data (future interventions and housing design). This information is then automatically translated into impact scores based on an expert informed quantification model. Table 1 shows the list of ecosystem services assessed using the NCPT and an example of a NCPT scoring outcome.

Table 1. Ecosystem services assessed using the NCPT and an example of calculated impact scores

Development Impact Score Average Per-Hectare			
Ecosystem Services Impact Scores	Max Possible	Adjusted Scores	Min Possible
1. Harvested Products	+0.04	+0.01	+0.00
2. Biodiversity	+3.77	-1.04	-1.23
3. Aesthetic Values	+0.36	-2.89	-4.64
4. Recreation	+3.01	-1.96	-1.99
5. Water Quality Regulation	+0.47	-0.88	-1.83
6. Flood Risk Regulation	+7.62	-0.20	-0.38
7. Air Quality Regulation	+5.51	+0.30	-2.49
8. Local Climate Regulation	+4.05	-0.94	-1.81
9. Global Climate Regulation	+4.52	-0.24	-0.48
10. Soil Contamination		+0.00	
Development Impact Score	+29.34	-7.83	-14.84

As illustrated in the example of Table 1 (not part of the analysis), the NCPT calculates the likely impact score of the proposed development on each of the 10 ecosystem services and also the overall development impact score (in the example this is -7.83). The calculated impact scores can be weighed and adjusted during the assessment to suit local conditions. One of the key reasons why the assessment is performed is improving the design of the proposed development: based on the tool impact score outcome, the proposed development design can be improved or revised to enhance multiple benefit provision in sustainable urban development. The NCPT can be applied at different stages of planning or development process to help improve the design along this process. In addition, the tool calculates theoretical minimum (-14.84) and maximum (+29.34) possible scores which show the potential of the site to lose or gain natural capital and associated multiple benefits, based on pre-development land use composition.

The “flood risk regulation” indicator is calculated based on a combination of factors: (i) the associated flood risk of each land use type, (ii) the flood risk zone classification (obtained by the Environmental Agency), (iii) the soil drainage classification and (iv) the local proportion of build-up areas. Although these four contributing factors can reliably describe flood risk within the determined area, the impacts of intensification or blue-green interventions on hydrology propagate outside this control area. For this reason, it was deemed necessary that this particular benefit (or dis-benefit) is assessed more precisely through hydrodynamic modelling (see section below).

Similarly, the control area boundary does not account for potential ecosystem connectivity with areas outside it. This is adjusted through correction factors (Holzinger et al., 2018). Impacts on health due to potential air quality reduction have been accounted through the population dynamics in the area.

Hydrodynamic Modelling

The hydrodynamic modelling was carried out using the CityCat model. In CityCat simulation of free surface flow is based on the full 2D shallow water equations. The solution is obtained using high-resolution finite volume methods with shock-capturing schemes. The sub-catchment area modelled is a 19.68 km^2 part of the Wandle catchment. The model uses the gauged flow at Beddington as an inflow boundary condition into the modelled region and models the surface water catchment to just upstream of the inflow from the Beddington Sewage Treatment Works.

The simulation was carried out for the 20/7/2007 event. The nearest rainfall station (Beddington) station measured 42mm of rainfall in 1 hour and 23.8mm in 15 minutes. This corresponds to approximately a 1:100 year 1 hour event. Measured 15 minute flow data from the Beddington gauging station was used as an inflow to the model. The DEM used 2m LIDAR data and buildings and green areas were extracted from the OS MasterMap dataset.

Figure 2 shows the maximum simulated depth for this baseline simulation. In total 4093 buildings were flooded to a high level (mean flood depth next to a building >= 0.1m and maximum flood depth next to a building >=0.3m). This scenario looks at surface water flooding excluding flow in pipes in the simulation. The locations of the flooded properties correspond well with the observed ones (Drain London, 2011). A similar model excluding flow in pipes has been used in the preliminary flood risk assessment (Drain London, 2011).

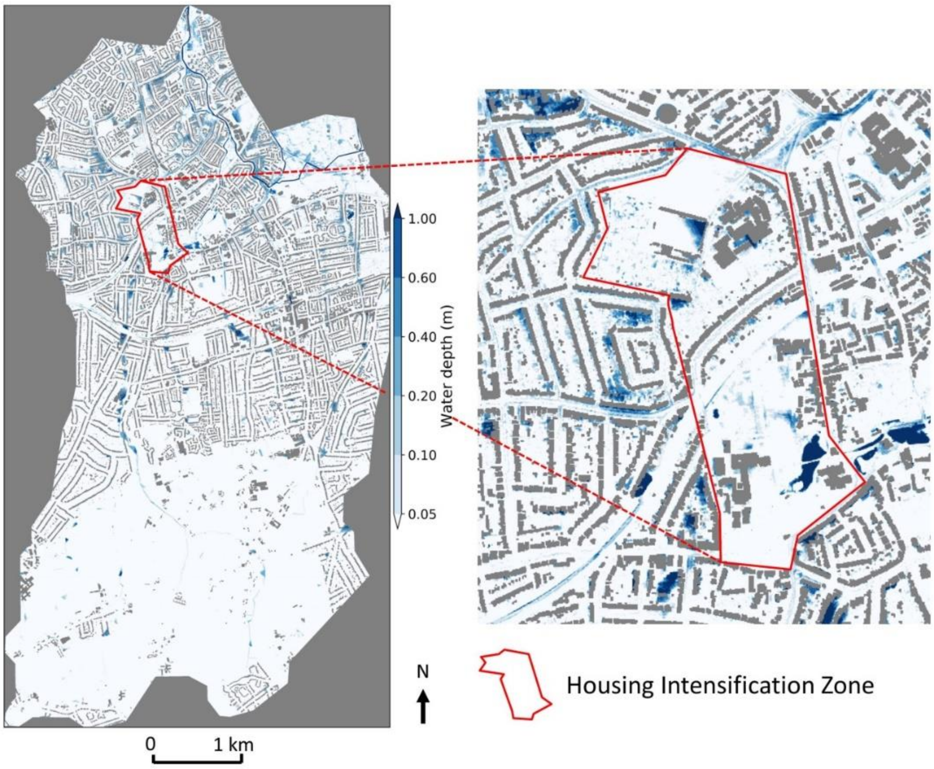
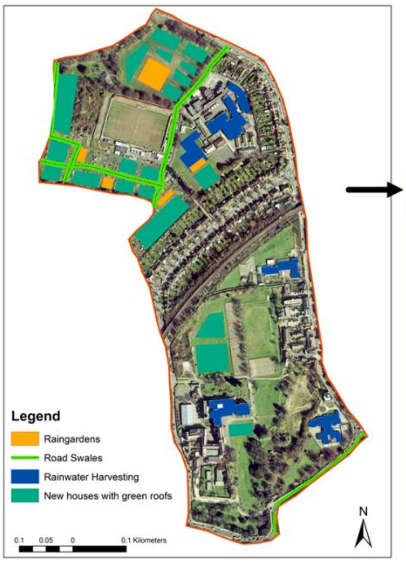


Figure 2. Example of water depth simulation by CityCat in the modelled sub-catchment under the current conditions.

RESULTS

Interventions

The location of the blue-green interventions is shown in Figure 3 (scores presented in the Figure are discussed in the following section). The interventions include a total of 1200 m of bio-swales which provide conveyance to the overland network. The network of swales discharges into the Wandle River further downstream. Rainwater Harvesting (water butts with potential for grey-water reuse) has been planned for retrofit buildings with a roof area more than 1,000 m^2. Their total area within the intensification zone amounts to 8,290 m^2. Green roofs are planned for all new buildings with a total area of 28,700 m^2. Finally, attenuating raingardens cover a total area of 3,895 m^2. These multi-functional areas offer multiple benefits and deliver a flood control service during rainfall events.



Development Impact Score
Average Per-Hectare

Ecosystem Services Impact Scores	Max Possible	Impact Score	Min Possible
1. Harvested Products	+0.16	-1.37	-1.37
2. Biodiversity	+4.16	-0.02	-0.84
3. Aesthetic Values	+4.48	+1.56	-3.52
4. Recreation	+6.40	-1.39	-1.60
5. Water Quality Regulation	+1.75	-0.43	-1.79
6. Flood Risk Regulation	+5.76	+0.05	-0.24
7. Air Quality Regulation	+3.17	-0.90	-2.94
8. Local Climate Regulation	+5.14	+2.37	-2.44
9. Global Climate Regulation	+4.44	+0.02	-0.56
10. Soil Contamination		+0.00	
Development Impact Score	+35.46	-0.12	-15.31

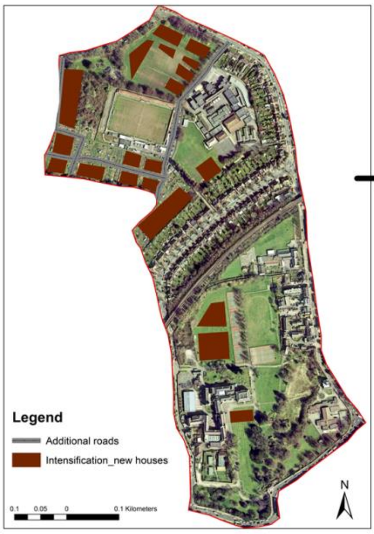
Figure 3. Combined impact of blue/green infrastructure options on natural capital and multiple benefit delivery

Development Impact Scores on Natural Capital

The likely impact of the proposed development was calculated based on different combinations of blue/green infrastructure options. These are presented in the sections below.

Grey housing intensification

The NCPT impact scores show that the introduction of grey housing infrastructure on greenfield sites will result in an overall negative development impact score on natural capital and multiple benefits (Figure 4). The results show that several multiple benefits will be lost; air quality and local climate regulation are particularly affected. Other multiple benefits to be lost/reduced include harvested products, recreation, aesthetic values, water quality regulation as the proposed development sites will replace part of existing natural capital in the area such as agricultural land under allotments, mixed woodland plantation and amenity grassland being used for recreational activities. In this development scenario, no new natural capital (green infrastructure) is included in the plan. However, the theoretical maximum possible scores show that there is potential to gain natural capital and enhance multiple benefit delivery if the proposed housing design/plan is improved or revised.



Housing intensification

Development Impact Score
Average Per-Hectare

Ecosystem Services Impact Scores	Max Possible	Impact Score	Min Possible
1. Harvested Products	+0.28	-2.13	-2.13
2. Biodiversity	+3.83	-0.74	-1.17
3. Aesthetic Values	+3.46	-1.87	-4.54
4. Recreation	+5.76	-2.24	-2.24
5. Water Quality Regulation	+1.32	-1.63	-2.22
6. Flood Risk Regulation	+5.63	-0.37	-0.37
7. Air Quality Regulation	+2.31	-3.80	-3.80
8. Local Climate Regulation	+3.82	-3.77	-3.77
9. Global Climate Regulation	+4.15	-0.80	-0.85
10. Soil Contamination		+0.00	
Development Impact Score	+30.55	-17.35	-21.09

Figure 4. Development Impact Score of grey infrastructure housing development on natural capital and multiple benefit delivery

Integrated blue/green infrastructure options

Four blue/green infrastructure options (new houses with green roofs, raingardens, road swales and rainwater harvesting) have been considered in this study as shown in Figure 3. The NCPT outcomes show that if the housing development is planned on existing green field sites but with an introduction of different green infrastructure options, the overall impact score of such a development will still be negative but less than the grey infrastructure scenario. Although the overall development impact is slightly negative, the introduction of green infrastructure yields positive impact scores on some multiple benefits such as local climate regulation and aesthetic values. Rainwater harvesting as a retrofit intervention can enhance natural capital by improving flood risk regulation. This suggests that a net benefit (as opposed to impact mitigation) can be possible in retrofit environments.

Individual blue/green infrastructure impact assessment

The NCPT outcomes show that individual blue/green infrastructure options have varying impact on natural capital and multiple benefits. All four options considered in this study have an overall positive development impact on natural capital and multiple benefit delivery except the green roofs option for the new houses (as the latter are delivered on land previously delivering significant ecosystem services). As Table 2 shows, rain gardens yield a positive impact on the delivery of multiple benefits such as local climate regulation and aesthetic values as this would enhance natural capital which previously was not there in the area and hence the associated multiple benefits. Similarly, the introduction of road swales (results not shown) has an overall positive development impact especially on multiple benefits such as air quality regulation as this is introduced on previously grey/concrete roads with no potential to deliver such multiple benefits. It is noted that the calculations on Table 2 are based on modifying the pre-development land-use only at the intervention location to isolate its impact; if “grey” housing was introduced in the calculation this would alter the results.

In contrast, the introduction of new houses with green roofs yields a negative overall development impact score and on most multiple benefits with a slight positive impact score on local climate regulation and aesthetic values multiple benefits. This shows that the natural capital value and multiple benefit delivery potential from the pre-development land uses (green field sites or allotments) is higher than the proposed houses with green roofs.

Table 2. Ecosystem service impact scores for each intervention alone on the pre-development land use

Ecosystem Service		Impact Score		
		Swales	Green Roofs	Rain Gardens
1	Harvested Products	0.00	-2.13	-1.23
2	Biodiversity	0.43	-0.31	0.30
3	Aesthetic Values	2.67	0.79	2.67
4	Recreation	0.63	-2.24	-1.50
5	Water Quality Regulation	0.00	-1.04	0.00
6	Flood Risk Regulation	0.00	-0.08	0.00
7	Air Quality Regulation	2.04	-1.76	-0.63
8	Local Climate Regulation	2.53	1.29	2.53
9	Global Climate Regulation	0.49	-0.31	0.49
10	Soil Contamination	0.00	0.00	0.00
*	Development Score	8.79	-5.79	2.63

Hydrodynamic modelling

Two scenarios were run using the CityCat model corresponding to the interventions described in the previous section. Firstly, the new buildings were added (grey option) to the model. Secondly the new buildings were included along with the blue/green infrastructure. The rainwater harvesting, green roofs and rain gardens were incorporated by removing the rainfall that fell on the specified buildings. In addition, swales were added as specified in Figure 3.

The difference in the maximum water depth between the grey intervention and the blue/green intervention can be seen in Figure 5. As expected, there is an increase in water depth in the swales suggesting they are performing their function. Elsewhere in the northern part of the intervention area there is a decrease in water depth which propagates downstream to the outlet of the modelled area. The swales here are doing an important job because as well as capturing the water that falls on this part of the intervention area they capture the water from west of the intervention area that flows through the intervention area. The interventions in the southern part of the area are less useful as there is no upstream area that flows through here, as well as reduced connectivity with downstream. Therefore, the reduction in water depths are mostly contained within the intervention area.

The reduction in water depth is generally small given the limited coverage of interventions, but it is enough to reduce the flooding at a high level by 15 buildings, whereas the grey option increased the flooding at a high level by 5 buildings.

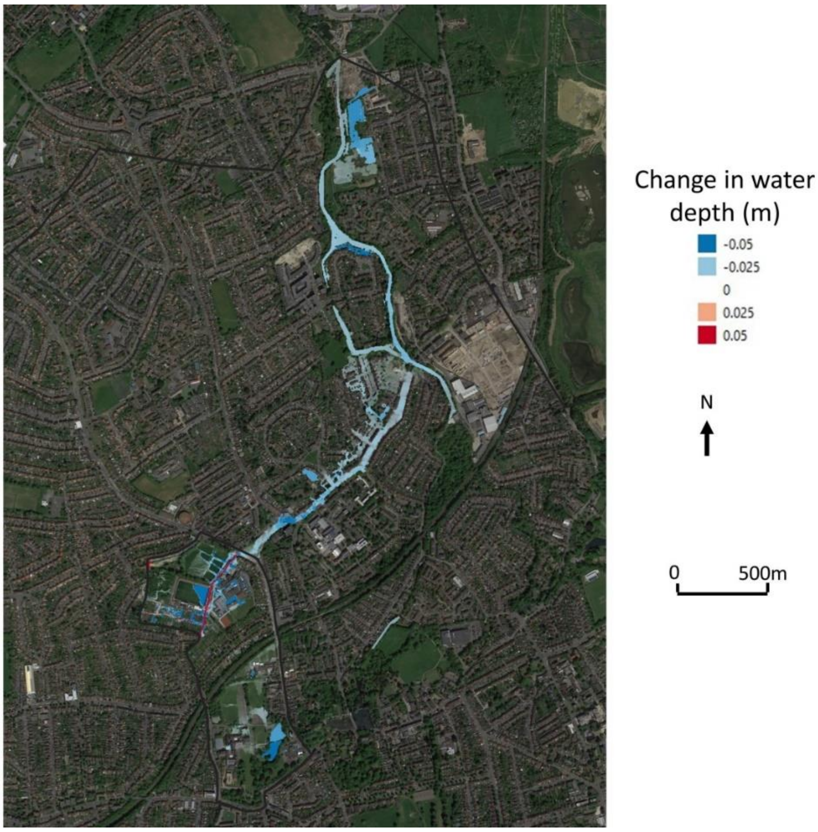


Figure 5. Change in water depth between the grey intervention and the blue/green intervention

DISCUSSION

The NCPT results show that imaginary new housing developments and associated grey infrastructure targeting open spaces and existing green field sites have a negative development impact on natural capital and multiple benefit provision over time. This implies that such grey infrastructure might have limited capacity in addressing future uncertainties linked to climate change (Depietri and McPhearson, 2017). Integration of different blue/green infrastructure options in developments, such as in Carshalton, does not only increase resilience to flooding (primary driver for intervention) but also delivers multiple benefits, thus enhancing the area’s natural capital.

Results from this study show that different blue/green infrastructure options have varying impact on types of multiple benefits delivered e.g. road swales have a higher positive impact on air quality regulation than the recreation multiple benefit. In addition, the spatial location of the blue/green infrastructure options influences multiple benefit delivery and in some cases pre-development land uses have more potential for multiple benefit delivery compared to the introduced "green-field" blue/green infrastructure options. This was the case of introducing new houses with green roofs on previous agricultural land under allotments and amenity grassland used for recreation activities. Findings from this study also show that retrofitting or introducing blue/green infrastructure in an area which previously did not have potential for multiple benefit delivery such as grey roofs and roads, enhances natural capital and multiple benefits delivery over time. The NCPT outcomes can also reflect tradeoffs and synergies in multiple benefits associated with different combinations of blue/green infrastructure options which, however, were not the focus of this work.

The key benefit driving the introduction of these interventions is the protection from flooding. The respective NCPT indicator is calculated using publicly available classification information on land use, soil type and flood risk zoning for the delineated intensification zone. However, the blue-green interventions and the intensification have flood risk implications on an area broader than the delineated, potentially across the downstream sub-catchment. Hydrodynamic simulations for the hydrological sub-catchment to examine how flood risk propagates away from the intervention/housing locations showed that grey development can increase flood risk downstream (4093 to 4098 properties) while blue/green development has the contrary effect (4098 to 4083 properties).

CONCLUSIONS

Preliminary conclusions from this study show that different blue/green infrastructure options have varying impact on natural capital and associated multiple benefits. It is also concluded that combining different blue/green infrastructure options can help retrofitting existing structures such as grey roads and roofs to enhance natural capital and multiple benefit delivery in urban development.

This study has demonstrated how natural capital assessments can be undertaken in practice to inform planning decisions and outcomes. When undertaken as part of wider environmental assessments, such an approach could ensure that natural capital is considered alongside built, financial, social and human capital in sustainable urban development in light of future climate change uncertainties. The NCPT used in this study can be used by both planners and developers to embed multifunctional blue/green infrastructure in sustainable urban development while also delivering on required societal needs. However, the NCPT has its own limitations related to the land use classification system that has limited applicability in urban contexts as it does not include all the habitat types associated with different blue/green infrastructure options. The choice of boundaries for the natural capital assessment is also critical to the final result, as benefits such as flooding and ecological connectivity, propagate further away from the development zone.

The natural capital assessment demonstrated in this study can improve understanding on impact of proposed developments on natural capital and associated multiple benefits in urban planning and development. The NCPT outcomes can offer options to consider different development designs to meet both environmental and societal goals. This can help practitioners such as local authorities, planning agencies, developers to understand the interdependency between the natural environment, economy and society in the planning process. Such findings can also be used for negotiations by practitioners to improve the natural capital and multiple benefit delivery performance of local future plans and developments in line with policy and legislative requirements.

Finally, it is recommended that the analysis presented in this work (based on land-use change impacts) is complemented by the use of other existing industry and research tools, such as spatial analysis tools (Morgan and Fenner, 2017) and the Benefits of SuDS Tool (CIRIA, 2018). The latter allows the monetization of intervention benefits such as the presented and can support building the business-case for Nature-Based interventions. Options cost assessments can value benefits in comparisons between blue/green and grey interventions or between different blue/green options.

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