Blue-green network planning as a spatial development and climate-resilient strategy - the case of Belmopan, Belize

Urban development and climate resilience through blue-green network infrastructure

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Abstract: Blue-green network planning seeks to protect the ecological and hydrological values of the urban landscape and to provide resilient measures to address climate change. UN-Habitat in collaboration with the Belmopan City Council and other local stakeholders, identified a blue-green network planning approach for the capital city of Belize, Belmopan. They developed a masterplan for the city that provides new strategies for managing urban flood risk, enhances the garden city character and promotes economic development in this newly developed city. Given the geography of the area, the city-wide strategy is based on the network of existing natural systems, multi-modal transit systems and public spaces in order to improve connectivity spatially and socially. Blue-green network planning involves using those blue, green and grey networks in the municipal and regional scale as structural elements and connecting them through a city-wide strategy. The blue-green network planning for Belmopan has a number of objectives. These objectives include to incorporate nature in the city; to enable social integration and spatial connection through public space; to maintain diverse productive urban agricultural landscapes; to rethink floodplain and drainage design; to target pollution resources and create storm water wetlands; and to enhance investment for nature protection and nature-based tourism.

Keywords: public space system; green space; water management; climate change; blue and green infrastructure planning; mixed-used development; active urban realm; green economy

1. Introduction

1.1. Background

In May of 2014, Belmopan, the capital city of Belize, developed a Municipal Development Plan (MDP) to address the city's major issues and to integrate environmental sustainability into city planning. It outlines the city needs and proposes projects to address these needs; however, the plan lacks a cohesive strategy to implement the projects and has no long term spatial plan for future development.

In January of 2016, UN-Habitat began working with the Belmopan City Council to further develop the MDP and in particular to create its spatial plan. To that end, UN-Habitat, in collaboration with Belmopan City Council, organized a series of workshops and a public consultation. The first workshop was held on April of 2016 and the public consultation was held the following year in March of 2017. The workshops gathered representatives of different national and local government institutions, the private sector, community groups, NGOs, planning professionals and academia to discuss the current situation and the future vision for Belmopan. The plans and ideas were shared with the participants during the planning process. After the workshops, the recommendations and comments from the participants were reviewed and the plans were modified regarding the feedback.

UN-Habitat planners and architects, together with hydrological experts provided by Arcadis via the joint UN-Habitat Arcadis Shelter Programme, worked with local stakeholders to propose a spatial framework using a blue-green network planning approach to complement the Municipal Development Plan. The framework features an integrated resilient master plan, and planning and design strategies to address the challenges described in the MDP. The work of UN-Habitat is generously funded in part by the Government of Norway through the agency's Cities and Climate Change Initiative.

1.2. Purpose

The paper aims to address current urban challenges in the city of Belmopan, Belize using the blue-green network planning approach. The paper will also recommend planning and design guidelines using the blue-green network planning approach.

1.3. Limitations and Scope

The research involved in the planning process has limitations. One limitation is that the primary source of information was maps generated by a Geographic Information System; additional ecological analyses that could help planners to better understand the environmental context of the city and to propose the most appropriate spatial plans were not available. Another research limitation is that further information on the climatic and wind environment are needed to further develop and implement some of the proposed strategies. In addition to understanding the ecological and hydrological context, it is useful to understand climatic data and wind flow information and apply it to the urban design process[2].

The paper explores how the blue-green network planning approach addresses urban challenges in the following categories: environment, climate change, culture and economy. The paper has five sections. Following the present introductory section, the second section defines the blue-green network planning approach. The third section describes Belmopan's major challenges in the aforementioned categories. The fourth section proposes strategies and spatial plans for Belmopan. The fifth section recommends next steps for the project.

2. Blue-green Network Planning Approach

2.1. Approach

The unprecedented rate of urban growth, coupled with current and anticipated effects of climate change and loss of habitat and biodiversity, demand innovative approaches to city planning that help cities to adapt to and mitigate the impacts of climate change and to protect ecosystems. According to the Intergovernmental Panel on Climate Change (IPCC) in 2014, "the next two decades present a window of opportunity for mitigation [and adaptation] in urban areas, as a large portion of the world's urban areas will be developed during this period"[1]. A growing number of cities are taking actions to achieve sustainable urbanization practices like expanding their green infrastructure to enhance climate-resilience, to complement conventional engineering solutions by maximizing ecosystem services and to invest in clean technologies. Blue-green network planning expands these efforts by including the rehabilitation and maintenance of the "blue" water cycle in urban areas as well as complementing conventional engineering solutions. These engineering solutions and man-made structures are referred to as grey networks. This "blue-green" planning process also prioritizes the quality of green spaces over quantity by focusing on upgrading existing green spaces. It acknowledges that cities are embedded in natural systems by examining a city's ecological and hydrological relationships.

The inclusion of water management in urban planning is increasingly important because of the flood risks imposed by climate change. Lawson warns that "concomitant increase in impermeable surfaces will further exacerbate the urban flood risk... and increase damages incurred, particularly in cities where the consequences of flooding are especially severe"[2]. Additionally, in many places climate change is expected to intensify precipitation causing more extreme flooding risks. Blue-green network planning seeks to update the "century-old" garden city in concept by protecting the ecological and hydrological values of the urban landscape, providing resilient measures to address climate change and improving quality of life.

Blue-green network planning consists of planning strategies based on blue water-based elements, green vegetation-based elements, green technologies and low carbon and climate-resilient infrastructure. Blue elements include streams, storm water drains, irrigation channels, wetlands, freshwater, sanitation and public spaces that can temporarily accommodate water overflow. Green elements include trees along streets, recreation zones, playgrounds, parks, forests, greenways and riparian strips. This planning approach also recognizes the continuum of human settlements and acknowledges that green, blue and grey networks extend beyond the boundaries of the city.

The blue-green network focuses on using natural systems in the region to structure the plan and the future development. It involves analyzing the spatial configuration and composition of the urban space, specifically integrated networks of green, blue and grey spaces relevant to the scale of analysis[3]. According

to Bacchin, blue-green networks address the "city (catchment), neighbourhood (sub-catchment), and community (micro-catchment) planning level and their interrelationships"[4].The blue-green network acts as a structuring element for the city at each of the three levels.

2.2. Environment

If not well-managed, the accelerating process of urbanization can have a serious impact across the urban-rural continuum and on the surrounding ecosystems. It causes fragmentation between cities and their surroundings, peri-urban, and rural areas. It also damages ecosystems through the degradation of urban ecosystem services and disruption of ecological processes. Blue-green infrastructure benefits the environment by enhancing ecosystem services and ecological connectivity. An exemplary blue-green network planning element is a green network or greenbelt. Ignatieva describes green networks as "creating physical, visual and ecological connectivity between built-up areas of the city and surrounding natural areas and greenspaces… while meeting the social and psychological needs of the urban population"[5]. Blue-green infrastructure also creates more sustainable urban hydrology by providing ecosystem services such as filtering contaminants, recharging groundwater and complementing man-made drainage systems in case of extreme storm events.

Well-designed and integrated blue and green networks promote connectivity which provides corridors for animals, improves habitat and increases qualities for recreation. An example of a green infrastructure element is a bioswale. Bioswales serve as a form of bioretention that enhances environmental quality by slowing, collecting, infiltrating and filtering stormwater. Since blue-green network planning generally combines ecosystem-based solutions with conventional engineering solutions, prior to incorporating bioswales into a blue-network plan, the water cycle within a local watershed and the current drainage system needs must be examined. Ecosystem-based adaptation ensures that ecosystems remain healthy which allows local populations to benefit from the provided environmental services including the provision of clean water and protection from extreme weather events[6].

2.3. Climate change

The blue-green approach is congruent with other concepts of urban sustainability like building climate-resilience and curbing greenhouse gas emissions. Urban resilience refers to the "ability of any urban system, to withstand and recover quickly from catastrophic events"[7]. Enhancing the climate resilience of infrastructure may involve, for example, constructing storm shelters in public buildings like schools and community centers, retrofitting buildings to withstand extreme weather, and safeguarding critical urban systems, road access and bridges. Developing low carbon infrastructure is another element of the climate change resilience strategy. According to Lehmann, low carbon infrastructure includes offering "a good public space network and multi-modal public transportation and improv[ing] streets by giving greater priority to pedestrians and cyclists"[8].

Blue-green infrastructure can help cities to mitigate and adapt to impacts of climate change, for example, increased precipitation and temperatures. Adaptive measures include flood risk management by increasing water retention and expanding drainage infrastructure. During periods of heavy rainfalls, wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant causing combined sewer systems to overflow and discharge excess wastewater directly to nearby water bodies. Blue-green infrastructure can reduce stormwater runoff preventing sewer systems from overflowing and complementing grey infrastructure. Blue-green networks can help to mitigate the urban heat island effect, which is expected to intensify due to climate change, through the provision of cool microclimates. Vegetated surfaces can provide shading, evaporative cooling, corridors for air circulation and exchange.

Green space and non-motorized vehicle infrastructure offer viable strategies for adapting to and mitigating climate change. Lehmann found that green spaces remain "one of the most cost-effective strategies for addressing the urban heat island effect"[9]. Improved sustainable transport infrastructure will reduce residents' reliance on motorized vehicles and limit the greenhouse gas emissions produced by vehicles. These strategies enhance resilience and adaptation to a changing climate. They will also improve public health by reducing risk of death during increasingly more frequent extreme weather events such as heatwaves. Urban climate change interventions need to be carefully adapted to local circumstances, access to resources while providing social and economic benefits for all urban residents[10]. This can be achieved by mainstreaming disaster risk, adaptation or mitigation into ongoing work and programs[11].

2.4. Culture

Well-designed blue-green networks engage communities with nature by increasing connectivity between neighbourhoods and parks. Access to these networks facilitates exercise and improves human health. The design of an individual's physical environment, particularly access to community services and public spaces, can influence social behavior and social interactions[12,13]. Well-designed networks also encourage community cohesion and social interaction. Improving blue and green infrastructure may also protect and nourish the cultural and spiritual values because these spaces of natural beauty have significance to the local community. Community gardens exemplify how green infrastructure can enhance social capital, facilitate social networks and improve the wellbeing of a community. These benefits included increased social cohesion, increased social support and social bonds and networks between those that participate in the garden[14].

2.5. Economy

Well-designed blue-green networks may provide economic benefits. Increased flood and storm risk will increase damage to property leading to costs from increased maintenance, operation and financial protection costs. Investing in this infrastructure may reduce flood-damage cost, giving a long-term solution instead of expensive post damage responses. It can promote economic development because of increased land value of properties overlooking the restored greenspaces and waterways. It can create opportunities for densification along the corridors, new space for economic activities at intersections and opportunities for commercial activity. Tourism may be enhanced because the city becomes more attractive and visitors are easily able to navigate the city on foot or bicycle. Additionally, there is potential for increased residential development through the creation of mixed use development as the city becomes a more attractive place to live, work and play.

3. Belmopan History and Challenges

3.1 History

The development of Belmopan, Belize originated from the need to move the capital city from the coastal city of Belize City to inland areas after Belize City was devastated by Hurricane Hattie in 1961 and other natural hazards. Given the number of large park areas with many flamboyant trees in the center of city, Belmopan was nicknamed "The Garden City". Belmopan was also envisioned to feature directed growth and development unlike the crowded conditions and unplanned sprawl in the old capital. The city of Belmopan is located south of Belize River and between the banks of Roaring Creek to the west and Mount Pleasant Creek to the east. The city's population is 17,000, and with a current population growth rate of around 6.26% the population is expected to double in about 12 years. Belmopan currently features relatively low density development given that the current density is 13.3p/ha and 44% of the municipal area is vacant land. The city's growth rate and amount of underutilized space highlight the need of regulation and management for the population growth allocation through the development of existing vacant plots as the city reaches its administrative boundaries.

Figure 1. Map of Belmopan's topography and main rivers

The city features a tropical monsoon climate under the Köppen climate classification. It has a lengthy wet season that typically lasts from May to February and a short dry season during the remaining two months[15].Given its classification as a tropical monsoon climate, the city continues to have precipitation during the "dry" months. This particular type of climate and the history of hurricanes underscore the need for an effective and sustainable stormwater management system.

3.1. Environment

At the national level, Belize is facing deforestation at 0.6% annual rate, renewable internal freshwater is declining, 38% of land under cultivation is prone to erosion, overexploitation of resources, increasing impacts of flooding. Surrounded by a series of rivers, Belmopan is particularly susceptible to land loss due to riverine erosion. This environmental degradation and fragmentation is mainly associated to expansion of agriculture, housing and tourism. This underscores the need to protect the local waterways from pollutants in the city's runoff. Increased stormwater runoff can cause erosion and transport toxins into waterways. The urbanization process often results in fragmented landscapes and isolated patches of habitat. This fragmentation decreases ecological services and biodiversity. The city also lacks proper land use planning in the recently developed extensions and linkage between economic development and environmental protection in development strategies.

3.2. Climate Change

In Central America, average temperature is expected to increase by as much as 4 to 5 Celsius degrees by 2100[16]. In the case of Belmopan, it is expected that the average annual temperature will increase by 3.5 Celsius degrees by 2090. Despite the fact that inland Belmopan is not exposed to sea level rise, there have been a number of other observed and projected climate-related challenges. The major impacts of climate change are warming temperatures, increased flood risk from more intense rainfall and increased storm risk from more intense rainfall and stronger winds[17]. Increased intensity of rainfall can cause flooding, including localized floods, from the stormwater runoff that flows off the impermeable surfaces in Belmopan. The city's drainage system is concentrated at the center of the city and does not extend to the urban fringes, resulting in frequent flooding in parts of the city. While at a global scale Belize's greenhouse gas emissions are insignificant, nonetheless under the 2015 Paris Climate Agreement all countries (and even cities) are urged to do their part to curb emissions[18]. All of these challenges may become serious issues if future urban development is not well-managed and planned.

3.3. Culture

In addition to the natural environment, the network includes the built environment like public space, community infrastructure and the social environment like programmes and social activities. The major cultural challenge is lack of access to public space and other community infrastructure. Although the city has a large quantity of public spaces, it lacks quality spaces and proper infrastructure for non-motorized transportation such as bike lanes or pedestrian walkways. There is an urgent need to improve public transportation, the quality of the public spaces city-wide accessibility, specifically access to public space and other community infrastructure. Land-use planning not only involves allocation of uses but also creating links between uses along the city creating a more compact, vibrant and liveable urban realm. Making the city more compact will allow residents to easily access their daily necessities and will promote social cohesion.

3.4. Economy

The blue-green network promotes mixed-use development along its corridors to increase density, promote economic development and encourage a new model for Belmopan. The objective of mixed-use development is to combine the physical environment with the living needs of the population. The blue-green network will be linked to the local university, schools, health facilities, recreation centers and governmental institutions. The blue-green network planning approach focuses not only on current residents but also on tourists. It enhances tourism especially nature-based tourism by investing in the nature protection and attracting visitors to explore the places of natural beauty. Other challenges include the lack of a city center, planned city infill/extensions and other economic activities that are concentrated in the flood prone areas and ecologically sensitive spaces.

4. Blue-Green Spatial Framework

4.1 Planning Process

UN-Habitat in collaboration with local stakeholders proposed a blue-green network planning approach to develop an integrated resilient master plan for the city, offering urban design tools to address the city's challenges. Per the request of the Belmopan City Council, the most important scale was the city-

wide scale as the spatial plan will be complementing the MDP which was developed at this scale. The Plan focuses on structuring the city's growth along development corridors that comprise of networks of existing natural systems, multi-modal transit systems and public spaces in order to improve connectivity spatially and socially. The process has been developed based on a scale approach ranging from the mentioned city-wide scale to the neighbourhood and community level.

The Master Plan becomes a guidance document to help direct future development projects in a comprehensive way. It suggests specific strategies to tackle the city's major issues. The Plan creates a foundation from which to further work on planning projects so that the future development of the city is integrative and climate-resilient. The vision for the masterplan is to use blue, green and grey networks as the planning elements. These networks are used to structure the city's development corridors. This approach to planning will help provide a prosperous, sustainable, climate-resilient and long-term future for the region by mainly focusing on development corridor infrastructure and integrating the natural systems, waterways and developed urban area.

4.2. Planning Strategies

UN-Habitat is working on a scaled approach by developing a spatial framework for future development based on the vision of their Municipal Development Plan. The framework is planned at city-wide level for the larger vision and through implementable pilot projects for short term action plan. The overall spatial framework includes three strategies to address the current and anticipated challenges of Belmopan. The three strategies, of which the second ("system of public spaces") corresponds of the "green" element of the "blue-green network," are as follows*:

4.2.1. Urban Connections

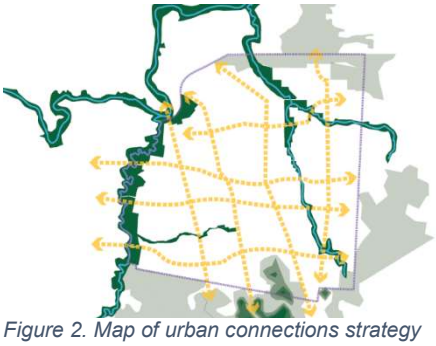

Figure 2. Map of urban connections strategy

A key factor for a successful city is its urban connections. Belmopan has become a disaggregated city due to its lack of structure. Improving connectivity would enable the city to become an integrated space and to promote social interactions. These connections are planned throughout the whole city and they link not only different areas of the city, but also the city with its regional area. This strategy is also designed to promote land mosaics. Land mosaics are the spatial arrangement of land uses for meshing and sustaining both the natural systems and people.

4.2.2. System of Public Spaces

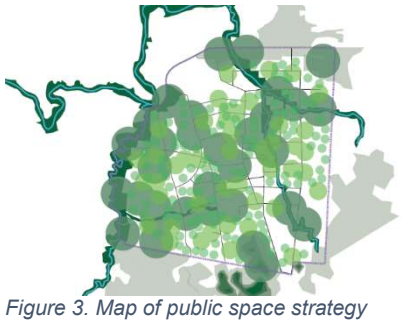

Figure 3. Map of public space strategy

Public space networks are critical elements of the blue-green network approach. One strategy to improve connectivity is to develop a system of public spaces. Public spaces range from riparian areas to small pocket parks; all of which will integrate the city at all scales. This strategy aims to incorporate natural systems into the planning and development of the city so that they become the backbone of the city. It aims to create spatial linkages through the existing and propose public spaces in the city.

*Maps are schematic/illustrative and not to scale. For to-scale maps that further develop these strategies, see the *Belmopan Urban Development: Towards a Sustainable Garden City Report.*

4.2.3. Mixed-Use Development

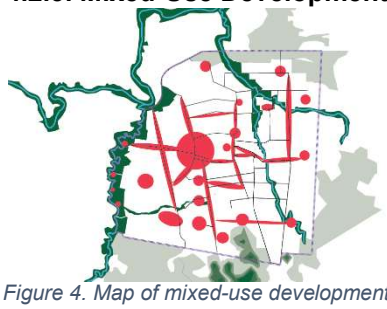

Figure 4. Map of mixed-use development

Another strategy to create urban linkages is to promote development along the city's development corridors. Following the network generated by the public space network and along the main arteries in the city, some potential nodes for mixed-use development have been identified.

This strategy aims to provide mixed services throughout the city so they are easily accessible for all residents, which would enhance social equity and spatial integration. This strategy is used to determine the most appropriate location for developing more mixed-use.

4.3. Master Plan

Based on these three strategies, the city-wide Master Plan for Belmopan was developed. As previously mentioned, it serves as a guidance document on how to spatially define and articulate the future urban development in the city based on the linkages between the blue-green network, the mixed-use development corridors and the residential areas. The Plan is comprised of different systems as per the key. The following is the Master Plan:

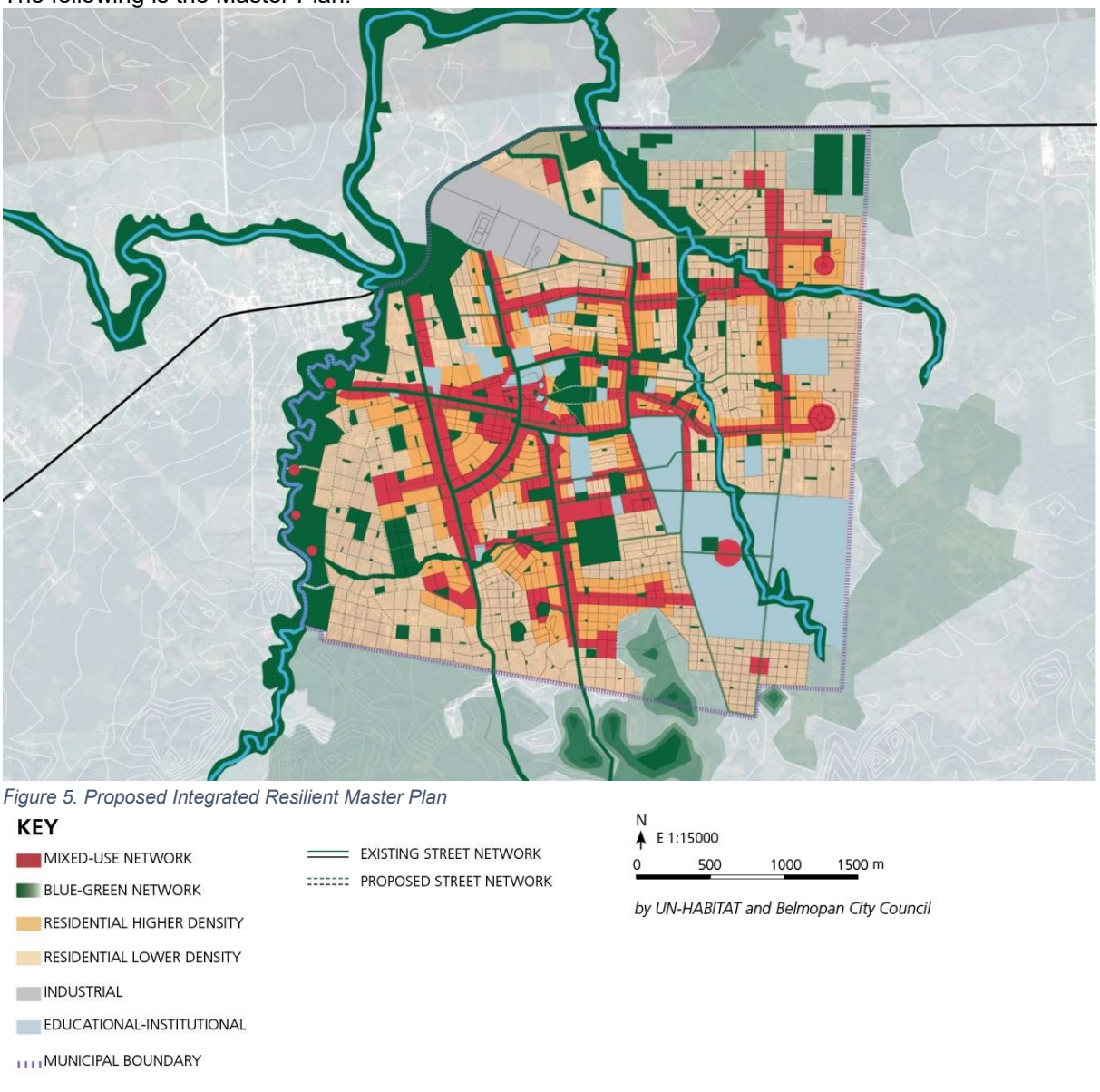

Figure 5. Proposed Integrated Resilient Master Plan

The blue-green network layer will be further explained based on guidelines and strategies on how to develop an integrative network of public spaces.

4.4. Blue-Green Network

Blue-green network planning involves using the blue, green and grey networks in the municipal scale as structural elements and connecting them through a city-wide strategy. It combines ecosystem-based adaptation planning, low-emission development strategies and man-made structures. Given the geography of the area, the city-wide strategy focuses on structuring the city's growth along development corridors that comprise of networks of existing natural systems, multi-modal transit systems and open public spaces in order to improve connectivity spatially and socially. Evaluating the elements and working at multiple scales is essential to addressing a city's priorities and challenges. They also explored design solutions at the district and neighbourhood scale. Specific urban planning and design solutions include protection of green areas, connectivity of public space, improvements to public transportation infrastructure, rehabilitation of waterways, increased roadside vegetation and development of multi-modal streetscape. The spatial design and allocation of these facilities at varying scales combined with the development of low carbon transportation will contribute to the success of the blue-green network in cities. It also contributes to making the city more environmentally conscious and creating a culture in which the residents actively participate in their community and positively impact their natural environment.

The case study of Belmopan exemplifies how blue-green networks provide synergistic management of, for example, urban stormwater runoff with green infrastructure. It illustrates how multi-value benefits can be achieved to meet the major urban challenges related to environmental protection, economic development and climate resilience. Blue-green networks can help Belmopan and other local authorities to address urban challenges and build resilience to the impacts of climate change.

4.4.1. Public Space and Social Programme ("Green network")

The first steps of this planning approach were to identify the current public spaces, agricultural areas and protected areas, and study how to spatially link them. This layer focuses on developing more spaces and improving connectivity between the spaces using three scales: city scale, neighbourhood scale and community scale. This layer of plan aims to meet one of the New Urban Agenda calls for action: "promot[e] the creation and maintenance of well-connected and well-distributed networks of open, multipurpose, safe, inclusive, accessible, green and quality public spaces"[19]. The following map shows the improved network of quality public space for use at the city-wide, neighbourhood or community scale.

At the city scale, the network includes open spaces along creeks and primary roads, spaces designed for particular activities such as the riparian recreation areas, bicycle lanes, pedestrian walkways, forests, city parks, botanical gardens, stadium, city market, urban agriculture production and tree planting along the roads. For the neighbourhood scale, the network features recreational spaces along the secondary roads. These spaces include sports fields, multi-purpose spaces, markets, plazas, urban agriculture, water parks, schoolyards or waiting rooms for public transport; all of which are spaces designed to be upgraded and provide services to small groups of citizens.

Finally, at the community scale, the network features small public spaces with uses like pocket parks, urban playgrounds, street micro-interventions, seating spots or reading areas. This enables people to easily make of their immediate urban surrounding a place to go, stay and interact with others.

The blue-green network for Belmopan addresses more than spatial challenges. It also fosters social inclusion and a sense of community as part of its Social Programme. This programme is developed for each of the scales and it is linked together within the broader city-wide strategy. The blue-green network aims to provide services for all residents. These services include recreation, community building, exercise and access to daily necessities while protecting the environment. One of the goals is to improve accessibility for the public space network through strategies such as increasing seating areas, building community gardens and developing large urban agriculture or markets. The programme also features other facilities like changing rooms, exhibition, research centers and reading areas. These spaces will host areas for physical, social and intellectual activities. In order to promote connectivity between the spaces, the programme proposes to add walkways and bike lanes to streets and develop comfortable waiting rooms

for public transport. This strategy also includes the concept of a bioregion. This involves developing design strategies based on the city's social patterns and cultural and bio-physical dimensions. It prioritizes both ecological and human flows.

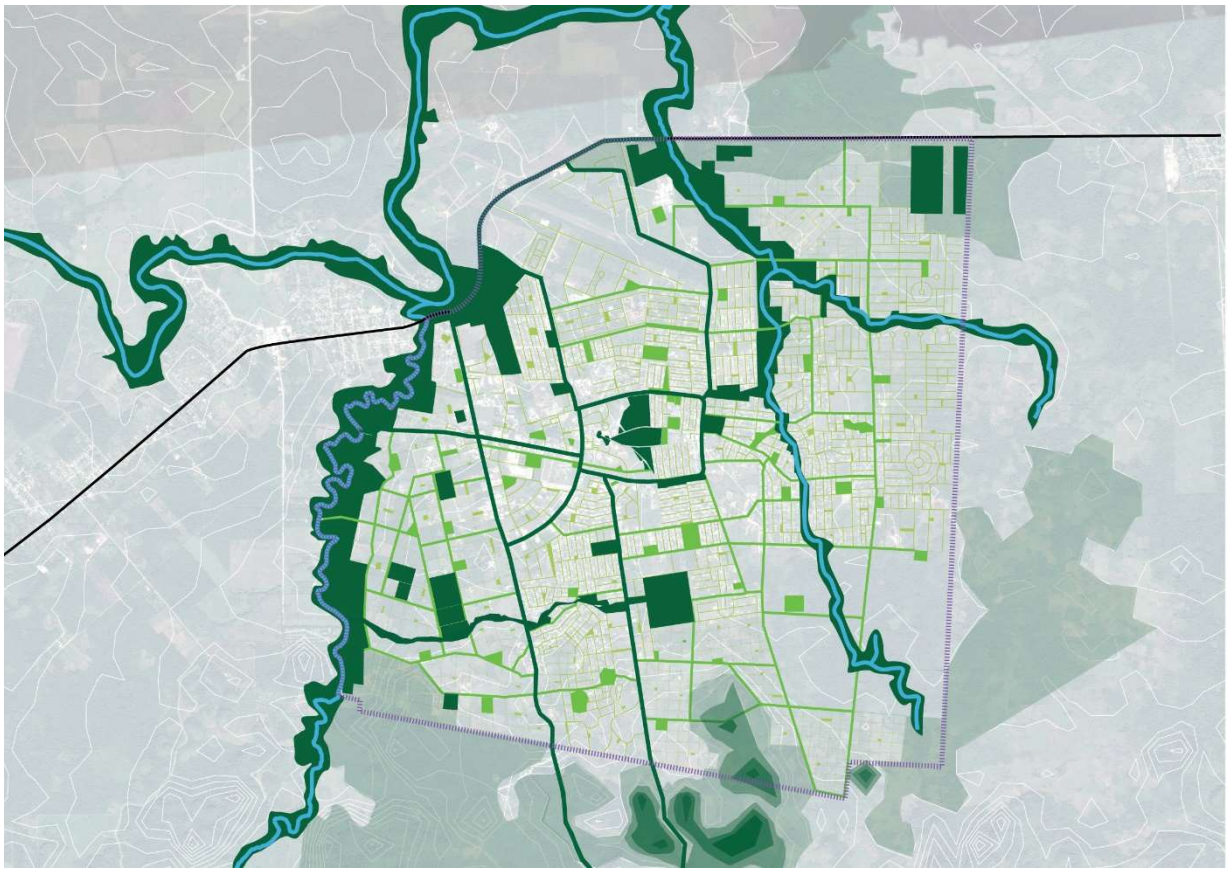

Figure 6. Proposed Public Space Plan

4.4.2. Eco-Mobility ("Green network")

A city-wide accessibility through eco-mobility was a main goal of the masterplan and a tool for an adequate design of the Blue-Green network. Proximity plays a key role in this strategy and so the network was planned based on walkable and bikable distances. Enabling walkability and cycling improves public health. It not only reduces pollution but also creates an accessible and inclusive urban space. The design of this infrastructure not only focuses enabling sustainable mobility but also place-making and creating liveable urban spaces.

The following diagram shows how the city's public spaces are accessible by foot and bike at different scales. It shows that a relatively high proportion of residents enjoy or will enjoy reasonable access to the community-, neighbourhood- and/or city-scale open spaces shown in the previous Figure 7.

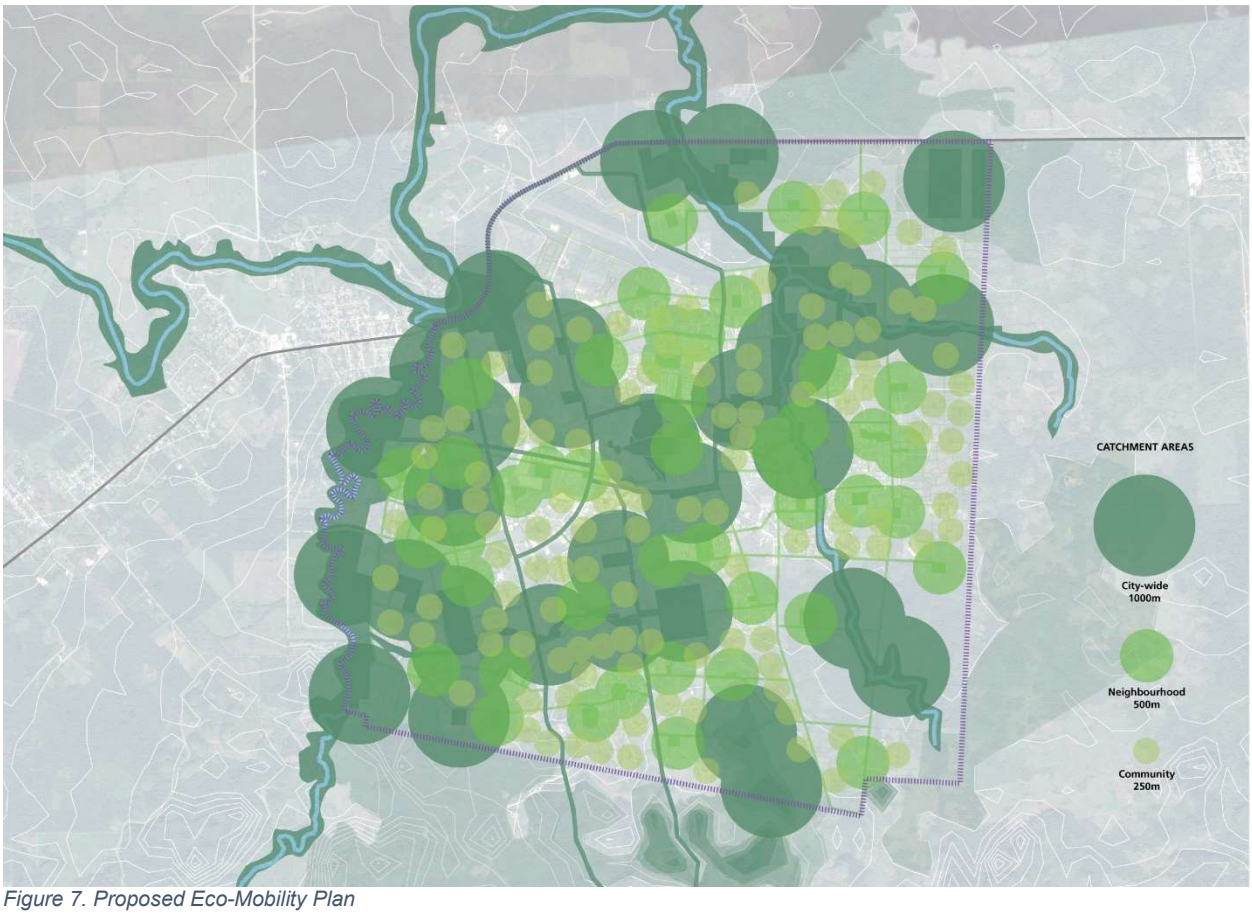

Figure 7. Proposed Eco-Mobility Plan

As previously described the whole network of public spaces is based on providing accessibility. For this to happen, a larger network of cycling routes and public transportation has been proposed. The starting point of the expansion should be along the main and secondary roads, as those are the ones addressing city-wide connections. This will also enable us to connect the main open public spaces. That is how the cycling and bus routes become an integrated part of the Blue-Green network as key elements of the public space.

The following map shows the existing and proposed cycling routes in Belmopan and the proposed network:

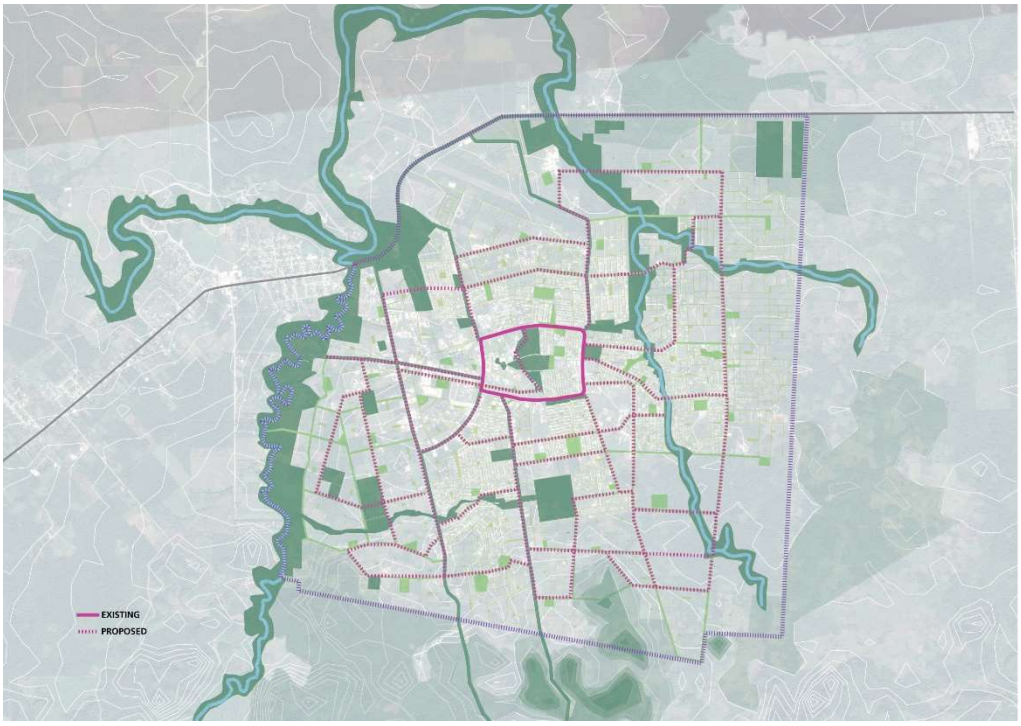

Figure 8. Map of Existing and Proposed Cycling Routes in Belmopan

The following map shows the existing and proposed bus routes in Belmopan and expansion:

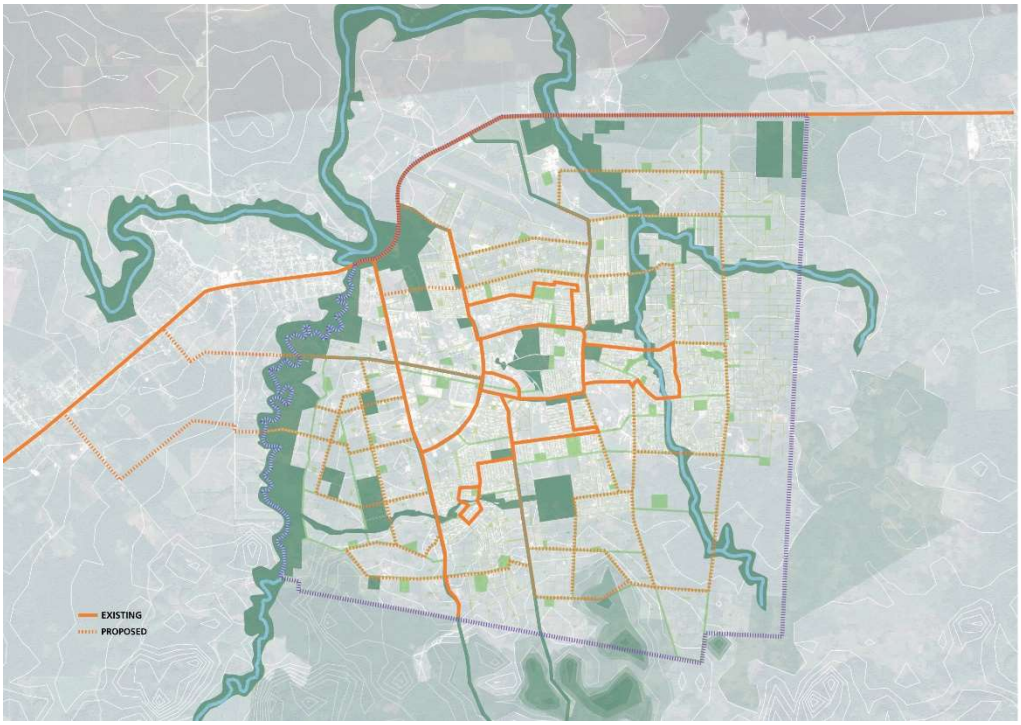

Figure 9. Map of Existing and Proposed Bus Routes in Belmopan

4.4.3. Water Management ("Blue network")

Increased development will require expansion of the current drainage system. Proposed standard and high flow drains correspond to the proposed street network, while proposed storage opportunities can be found in neighbourhood- and city-scale public parks. The goal of the proposed drainage system is to provide stormwater relief to the city while promoting the use of low impact development best management practices (LID BMPs) to maintain the natural water balance of runoff and infiltration. In general, development increases the area of impervious surfaces in a city, resulting in greater flows of stormwater runoff, which may cause flooding if there is not adequate capacity to carry the increased flow. The proposed LID BMPs aim to reduce both the volume and the velocity of the runoff to prevent such impacts. Increasing private stormwater collection (i.e., cisterns, rain barrels) and reducing the area of impervious surfaces (via permeable pavement, green roofs, etc.) help to reduce the volume of runoff produced. Directing runoff through vegetated channels also helps decrease the flow by slowing the water and allowing for increased infiltration. Managing stormwater near its source via temporary or permanent storage can be used to increased infiltration (in retention ponds) and manage releases (from detention ponds) to reduce overall peak flows and improve water quality.

The map below identifies three main categories of proposed drains: covered drains, bioswales, and infiltration trenches or subsurface drains. In general, covered drains are suggested for improving existing concrete-lined trenches to increase the connectivity between pedestrians and public or commercial spaces. Infiltration trenches and subsurface drains are suggested for higher density residential and mixed use areas. The goals of these BMPs are to promote infiltration where possible and convey excess runoff when necessary, while improving the aesthetic appeal, functionality, and safety of pedestrian spaces. Bioswales are proposed for lower density residential areas where there is adequate space to create wider, vegetated channels without obstructing access to public or commercial spaces. The map also identifies potential temporary or permanent storage opportunities at the neighbourhood and city scales that can help prevent streams from overflowing during peak flows by retaining water onsite while providing recreational and aesthetic benefits to the parks.

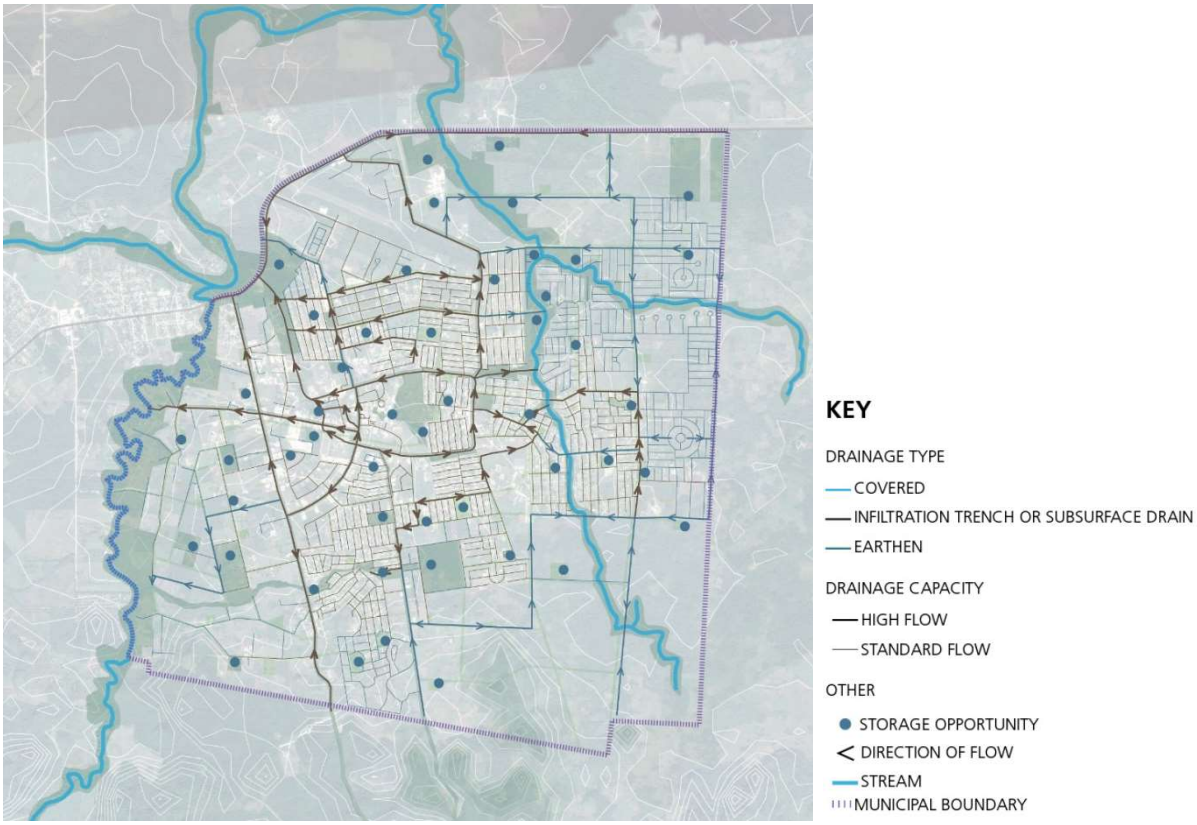

Figure 10. Existing and Proposed Drainage System and Flow

It is important to note that infiltration options may not be the best alternatives if the soil permeability is low. Though a comprehensive soil survey has not been performed in Belmopan, there has been success with infiltration-based BMPs in areas with similar limestone-based geological features where minimum infiltration rates of 0.5 inches per hour were found Horner, W. R., and A. Potts. "Infiltration Techniques for Stormwater Management in Carbonate Geology." World Water & Environmental Resources Congress 2003. ASCE Library. Further soil analyses are needed in Belmopan before any infiltration trenches or dry ponds are considered. The map suggests an option based on the general principles of the integrated stormwater management approach described above.

4.4.4. Environmental and Climate Change Programme ("Blue-green network")

The planners specifically used the natural systems in the region to structure the plan and guide the city's future development. The city has potential for further integration of green infrastructure into the built environment and the surrounding natural systems. The connection between these elements and the steady growth in urban residents helped drive UN-Habitat's planning process. Data on green, blue and grey infrastructure is collected and used to select the climate-resilient design strategies that are most appropriate to the planning scale. The proposed strategies will help Belmopan to avoid the detrimental environmental impacts of urban sprawl and impacts of climate change. Poorly designed and managed cities produce the numerous environmental and climate change challenges and so these strategies are to be included in further detailed projects, which will address these challenges. These strategies for addressing environmental and climate change challenges will be developed through each of the components of the blue-green network: public space, water management and eco-mobility.

In order to curb greenhouse gas emissions, Belmopan needs more infrastructure for sustainable modes of transportation as an alternative since the city has been planned and developed mainly for private vehicles. Non-motorized transport will help to reduce air pollution and costs for residents especially young and low-income people. The current city layout lacks an adequate multi-modal transportation system. The development of sustainable transportation infrastructure will facilitate a healthier way of life for citizens and reduce exposure to air pollution.

Expanding and improving sidewalks, cycling lanes and the current bus lines, in addition to green areas, as proposed in the previous maps, will greatly impact city life by improving public health and environmental health. According to Baldauf, vegetation barriers "can improve near-road air quality and can affect the public health positively for populations near high-volume roadways"[20]. The design and quality of these transportation systems need to be prioritized as its development is essential to address the major challenges and needs of the city. The spatial design and allocation of these facilities combined with the development of low carbon transportation will contribute to the success of the blue-green network in Belmopan. One design strategy is to connect the isolated patches using green corridors. The benefits of connectivity may be increased biodiversity, protection for nature reserves and enhanced ecological corridors and riparian margins. Some design strategies to address water pollution include connectivity of waterways, riparian vegetation and stormwater retention basin. These strategies reduce water pollution and runoff by stabilizing the banks of the local waterways and filtering the stormwater.

In order to address the increased storm and flood risk caused by climate change, the design strategies like stormwater retention basins are featured to increase the city's capacity of water retention. These floodplain design features reduces flood-damage costs. In order to further reduce infrastructure and services costs, the plan proposes concentrating growth along development corridors. Green networks are another design strategy that can increase the city's capacity to absorb water during heavy precipitation.

The plan proposes features to address the urban heat island effect which is exacerbated by climate change. It features blue networks like water bodies to transport cool air into the city. Increasing green networks like tree corridors provide cool microclimates from shading and the evaporation of water through plant leaves. Urban airflow is also an important element of climate sensitive urban design. Cold air ventilation channels like small areas of vegetation can be positioned based on the climatic data and wind information allowing for the penetration of cooling winds though the built environment. Additional analysis is needed to develop the global strategies in specific projects. The next steps of this project are described in the Recommendations Section (Section 5).

5. Recommendations

Additional analyses and studies of key components of the natural and urban environment in Belmopan are recommended to further develop proposed planning recommendations and strategies. Regarding ecological systems, it is important to better understand the native species and the flows of the fauna and flora so that the natural ecosystems and its elements are adequately incorporated into the blue-green network. The wind that flows throughout this network of public spaces is also relevant. Analyzing and mapping the wind flows in the city and its surroundings will help determine the planning of the green spaces and water bodies so that these features can effectively enhance air movement and cooling. Furthermore, when planning new development areas, this information will be essential to selecting the optimal orientation of the streets. Studies on soil types are recommended because the infiltration capacity of the soil is needed for the planning process of a new drainage system for the city. Soil information is also needed when selecting retention areas, which will help to address the increasing heavy rainfalls. Lastly, public participation workshops and consultations with residents is highly recommended to allocate adequate social programme for the blue-green network. The social programme is designed to meet the needs of the residents and so this participatory process is key for its success.

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A biographical note on the authors:

Marcus has been working for over 10 years as an urban and regional development specialist in various positions and countries around the globe. He received a masters from the Technical University of Berlin in Urban and Regional Planning and has a broad experience in advising national governments and city leaders internationally. His current role with UN-Habitat involves developing plans, strategies and actions that meet clients' needs, address their objectives for sustainable urban development and tackle climate change. Previously, he has been the Urban and Regional Development advisor at the German Corporation for International Cooperation (GIZ) and at United Cities and Local Governments in Spain.

Clara has been working for nearly a year in UN-Habitat being an active member in different programmes: the Urban Planning and Design Lab, the Climate Change Planning Unit, and the Public Space Programme. Her work focuses on urban planning and design based on its spatial, social and environmental approach from the city-wide to the community scale. She received a master's in Architecture from Seville's Architecture School. She previously worked as an architect for international architecture firms, Nabil Gholam Architects and FTCA Arquitectos.

Chandra currently works with cities to address the climate challenge and implement the Paris Agreement on Climate Change. Prior to interning with UN-Habitat, she interned as a sustainability consultant at firms including Siemens and CH2M Hill. Through her academic research and professional career, she seeks to reimagine and redesign space including physical, social and virtual to make cities more sustainable, just and climate-resilient. A graduate of Duke University with a degree in environmental sciences and policy with distinction, she will be pursuing a masters in urban planning at the Harvard Graduate School of Design starting in the fall of 2017.