ARUP

Arup Global Sponge Cities Snapshot

Using digital tools to understand the natural absorbency of cities to cope with increasingly heavy rainfall

Contents

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Introduction

Cities can't go on being concrete jungles, in conflict with nature. To flourish, cities need to work 'in tune' with nature. They need to learn quickly how to deploy nature-based solutions that bring far wider benefits than traditional engineered 'grey' infrastructure and contribute positively to biodiversity and carbon reduction. There's good news – powerful new digital mapping tools now exist to help us understand cities as complex systems, allowing us to adopt nature-based solutions in our projects. This now needs to be accelerated on a global scale.

We have developed the Global Sponge Cities Snapshot to highlight the importance of understanding a city's natural ability to manage heavy rainfall, as a critical first step to enhancing this ability. It does not answer all the questions, but it is aimed at accelerating a much-needed conversation – giving cities more insight into their existing blue and green infrastructure. Our message is simple: cities need to be asking – 'how spongy am I?'. We need to get used to measuring and understanding our existing blue and green infrastructure to help us strengthen it. Our green and blue assets – grass, trees, bushes, lakes and ponds – need to be quantified and valued in the same way we have treated other resources, such as pumps and concrete pipes.

This report is focused on looking at the value of blue and green features in helping cities tackle storm events. Nature-based solutions can also be applied to a whole host of problems that climate change will bring such as extreme heat and drought. As well as fighting to keep global warming to below 2 degrees Celsius, we need to build the resilience of our cities and communities in dealing with the effects of climate change. One of those major risks is flooding.

Our survey ranks the current natural absorbency or 'sponginess' of several cities from around the world. It has been compiled using our digital tool, Terrain, and quantifies the amount of green (grass, trees) and blue (for example, ponds or lakes) infrastructure in the urban centre of the cities versus the amount of grey (buildings and hard surfaces). It considers a multitude of land 'types': not only identifying greenery in public park lands, but also in private gardens and around buildings.

Once we know our natural baseline, we can then understand better how to enhance, extend and work with these natural assets. We have the power to harness this natural absorbency, moving away from the reliance on some of the traditional engineered 'grey' solutions that are not necessarily best equipped to deal with the effects of climate change, including pumps, pipes and storage tanks. I hope this report starts a conversation and gives people an understanding and confidence that nature-based infrastructure solutions can be deployed, bringing more resilient, cleaner, healthier, and happier cities.

Mark Fletcher
Arup Global Water Leader

Greener Grangetown
As part of the Greener Grangetown project in Cardiff, UK, 'rain gardens' have been created to slow rainwater run-off flows, removing more than 40,000 cubic metres of rainwater each year from entering the combined sewer network. Read more.

Foreword

For millennia, civilisations across the world learned to live with and utilise the nature around them – from ancient irrigation systems to present-day rainwater gardens to manage rain water. Under the influence of climate change and rapid urban development, the problem of urban stormwater systems is particularly serious, showing many problems such as frequent flood disasters, water environment deterioration, water resource shortage and water ecological destruction.

The nature based solution based on natural sponging improves the toughness of urban rainwater system from two perspectives of 'adaptation' and 'mitigation'. Although on the whole, it is a common consensus to improve the urban rainwater system by combining blue, green and grey, different countries or cities have developed and implemented different standard systems according to their own conditions, which leads to certain differences in management modes and actual effects of stormwater control. In fact, different cities and their regions have different problems, characteristics and goals. I think sponge city is multi-objective and can be adjusted according to the actual situation. Sponge city can be applied to any climate and geology conditions.

The Global Sponge Cities Snapshot study helps highlight the opportunity for cities to move away from the unsustainable and costly interventions, towards green and blue solutions. I hope cities across the world take notice and find ways to better ultilise their natural assets.

Professor Li Junqi
Beijing University of Civil Engineering and Architecture

> 'For millennia, civilisations across the world learned to live with and utilise the nature around them'

Professor Li Junqi, Beijing University of Civil Engineering and Architecture

How we rated the cities' 'sponginess'

How spongy is my city? What is its natural ability to absorb rainfall?

These are questions that cities need to be asking themselves if they are to cope with one of the major impacts of climate change – increased flooding. Using the survey as a 'lens', we have set out to shed more light on the natural absorbency of cities around the world and their natural ability to manage increasingly heavy and sustained periods of rainfall.

We examined diverse cities across the world with different urban profiles – from the densely packed Mumbai to Auckland, which is known for its generous public parklands.

We have given each city a sponginess rating based on three major factors: the amount of green and blue space within the urban environment; the hydrological properties of the soil in each city, and the water runoff potential for green areas.

1. Measuring the amount of green and blue space using our advanced digital tool

We have set out to rapidly and accurately measure the trees, grass and waterbodies in the urban centres of the cities to get a far better understanding of their natural absorbency. We have calculated this using our sophisticated digital mapping tool, Terrain, which uses machine learning techniques to produce a high-quality land use assessment from satellite images.

To carry out the analysis, we secured detailed satellite imagery for each city from commercial and open sources. We ensured that this imagery covered approximately 150 square kilometres over a city's main urban centre, to provide a representative study area.

We then trained the machine learning model to recognise multiple typologies – between 8 and 15, depending on the city – for example, low rise residential, tower blocks or urban parks. We then took samples from each typology and for each of the samples we measured the amount of grass, trees, water bodies and 'grey infrastructure' – hard paved surfaces and buildings. This gave us an average amount of blue, green and grey infrastructure for each typology in each city, which can then be multiplied by the amount of each typology in the city – giving us a breakdown of green, blue and grey surface areas for each city.

2. Accounting for soil types

Once we had the percentage of blue, green and grey spaces for each city, the next step was to factor in the impact of different soil types and vegetation in each city.

Using a global database of hydrologic soil groups (HYSOGs250m), we were able to calculate the amount of each major hydrological soil type present in each city. Soil types have a significant impact on the amount of water runoff and therefore a city's sponginess. This can be due to the soil type and texture – for example, sandy soils are 'spongier' than clay-based soils; as well as depth of soil and depth to the water table – for example, a groundwater table close to the surface reduces sponge capacity of the soil.

3. Calculating water runoff potential for green areas

With the impact of soil type factored in, we then used the Curve Number method – a simple, widely used method – to calculate the amount of runoff from a defined rainfall event.

Imagine rain falling onto a surface: it is either absorbed or 'stored' in the soil – potentially adding to groundwater stores – or slowly makes its way to water bodies. Alternatively, it runs off the land and therefore contributes to storm flow and potential flooding: this is the rainfall runoff potential.

The amount of runoff is affected by the vegetation cover; in our examples, we considered whether the soil was grass covered open space in 'Fair Condition' or a tree-grass mix. Rainfall runoff potential also varies according to the amount of rain that falls, so for our calculations we looked at the runoff potential for 50 mm of rain falling in a day for each city – this would be equivalent to a 1 in 5-year rainfall event in London or an annual event in New York. For blue spaces within the typologies, the assumption is that all the rainfall is absorbed.

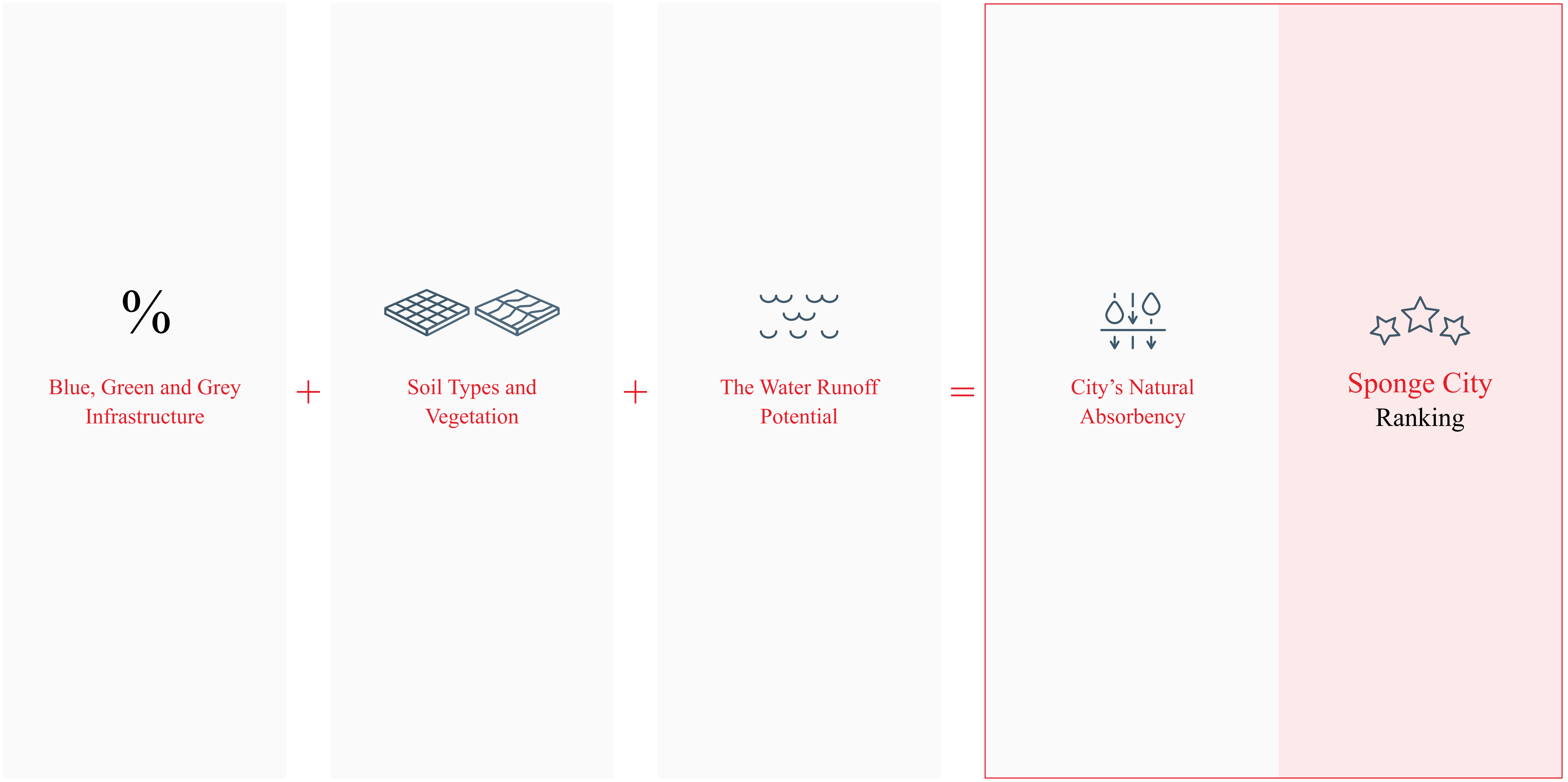
How we rated the cities' 'sponginess'

Sponge Ranking Overview

In summary, we calculated the percentage of blue, green and grey infrastructure in a city, factored in the impact of soil types and vegetation, and finally the water runoff potential. We then used this to produce a calculation of a city's natural absorbency from its green and blue spaces – and the greater the natural absorbency, the higher the sponge ranking.

We would recommend cities also consider factors such as sewer network capacity or flood storage areas. In this study we do not consider the comparative performance of the cities' built environment, e.g. stormwater sewer network capacity or rainwater harvesting potential, in managing heavy rainfall. We have excluded the main waterbodies from each city, such as the Hudson River. This is to try to avoid main waterbody areas distorting the results for this study. Where water bodies are assessed within other typologies such as lakes or within parks, then these are retained.

What this survey provides cities is a good indication of their baseline as a step to building a comprehensive plan to enhancing their nature-based infrastructure.



Sponge Snapshot results

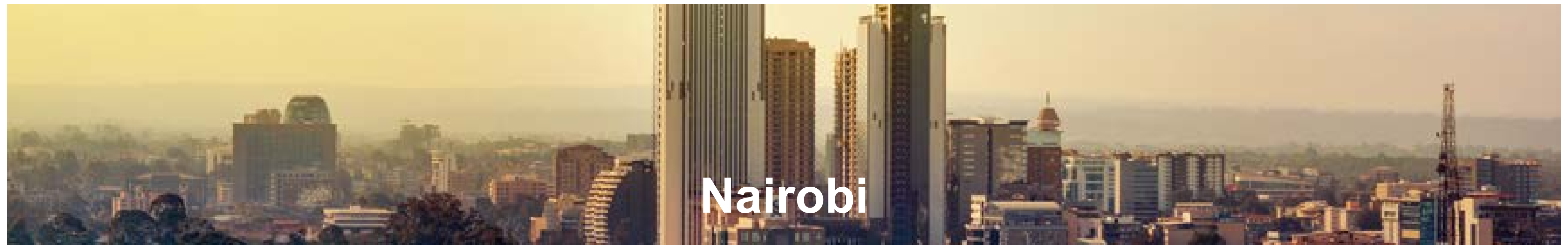
What we found

We evaluated each city's overall 'sponginess' based upon three factors:

– Amount of blue and green space
– Soil type factors
– Water runoff potential

City	Sponge Ranking	Overall % 'sponginess'	Green-Blue Area %	Soil Classification and Runoff Potential	Notes
Auckland	1	35%	50%	Moderately-high runoff potential (<60% sand and 10-20% clay)	
Nairobi	2	34%	52%	High runoff potential (<50% sand and >40% clay)	Shallow soils and depth to bedrock
Singapore	3	30%	45%	Moderately-high runoff potential (<60% sand and 20-50% clay)	
Mumbai	3	30%	45%	High runoff potential (<50% sand and 20-40% clay)	shallow soils and water table and/or depth to bedrock
New York City	3	30%	39%	Moderately-low runoff potential (40-70% sand and <10% clay)	
Toronto	3	30%	39%	Moderately-high runoff potential (<50% sand, 20-40% clay)	
Montreal	4	29%	36%	Moderately-high runoff potential (<50% sand and 20-40% clay)	
Shanghai	5	28%	33%	Moderately-high runoff potential (<50% sand and 20-40% clay)	
London	6	22%	31%	Moderately-high runoff potential (<50% sand and 20-40% clay)	
Sydney	7	18%	24%	Moderately-high runoff potential (>60% sand, 10-30% clay)	

Sponge Cities



Auckland

Auckland

Area surveyed

The most populous urban area in New Zealand, Auckland has an urban population of around 1.4 million. Auckland is one of the few cities in the world to have a harbour on each of two separate major bodies of water. The study area featured central districts including Newmarket and Mount Eden. It is dominated by low-rise residential properties, with a significant proportion of medium-rise commercial buildings. As well as featuring Mount Wellington, there are a number of green spaces across the area, including parks and golf courses.

Flood risk

Auckland has experienced heavy rain events, storm surges, coastal inundation and droughts, which are expected to become all the more frequent.

Since 2010, over 14% of all natural disasters that have occurred in New Zealand have been in Auckland, ranging from flooding to extreme weather such as tornados.

Given rising sea levels and predictions of a temperature increase, without action, the rainfall could exceed the capacity of current stormwater systems and result in surface flooding.

Sponge ranking

Despite having a high volume of low-rise residential developments, there is an abundance of green infrastructure spread throughout Auckland, with housing often including good-sized gardens, and large urban parks featuring across the city. It is the green areas within the low rise residential that have helped the city have a high green-blue percentage, second only to Nairobi. The recently announced National Policy Statement on Urban Development has allowed conversion of low density residential areas to medium density up to three storeys, which is expected to create significant changes to the urban form in Auckland.

Industrial parks lack green infrastructure, but these are clustered and often border parkland, grassed areas and farmland. All of these factors have helped Auckland, a low-lying coastal city with an annual average rainfall of 1210mm, rank more highly in our survey.

The city benefits from stormwater management initiatives which are currently undertaken by the Auckland Council. These include mandating detention and retention of stormwater runoff in specific areas, promotion and defined processes for Water Sensitive Urban Design and a comprehensive Network Discharge Consent which leans heavily on retaining and restoring the natural hydrology of sites.

This reflects a city generally well-prepared for significant levels of rainfall, and that is important given the maximum amount for an hour period in an average year is 20.6mm.

The city's top 'sponge ranking' was achieved primarily due to the high percentage of green-blue surfaces, even after excluding the harbour from the calculations. Much of the soil within Auckland's central Isthmus has relatively high infiltration potential within pervious areas. There are several suburbs within the study area where disposal to soakage is often the primary means of stormwater management.

It is worth noting the study assessed that Auckland had a lower percentage of trees compared to New York, Singapore and Mumbai.

City Dashboard

Auckland Analysis

Ranking 1st

Sponge Percentage

35%

Permeable Surfaces

50%

Green / Blue

Soil characteristics

Moderately-high runoff potential

<60%
Sand

10-20%
Clay

Click onto the map to expand


London

London

Area surveyed

The UK's capital, London, is a low-lying city crossed by the River Thames flowing through it, dividing the city into north and south.

The city is dominated by medium density urban typologies that were assessed as having relatively low proportions of green-blue areas within them. Urban parks and low rise residential are the next largest typologies. London benefits from its urban parks being well spread across the study area and it is these that contribute the most to the green-blue percentage of the city.

The rainfall profile of London is relatively constant during the year, with the maximum rainfall level for an individual hour each year in London typically being around 7.4mm.

Flood risk

London has experienced recent events of flash flooding, and in 2021 was hit with rainfall levels much higher than usually found when 47.8mm of rain fell in a 24-hour period - most of it in just one hour.

It left roads flooded, people needing to be evacuated from their homes and train services cancelled. Damage to businesses, infrastructure and residential buildings was estimated to be in millions of pounds.

The Thames Barrier is one of the largest movable flood barriers in the world, protecting London from tidal surges and has operated over 200 times since its construction in 1982.

With climate change and sea level rises, it is predicted that the frequency of occurrence of these flash flood events will be more common in the future, through increased winter rainfall and more intense summer downpours, leading to a risk of flooding and storm surges.

Sponge ranking

London was ranked second lowest in our 'sponge ranking'. The data suggests the city scored lower because it has fewer green-blue areas at just 31% compared to Shanghai's 33%.

The type of permeable surface also plays a part. The study assessed that there is a smaller amount of tree coverage compared to Shanghai. However, it is interesting to note that the London sample area had more trees than Auckland and Nairobi.

The city only has a mid-ranking soil type similar to Auckland, Singapore, Shanghai and Sydney. However, its soil was assessed as being slightly more permeable, meaning less water runoff than Mumbai and Nairobi. In conclusion, it is the lower quantity of green-blue area, including lower proportions of tree coverage, that resulted in London having a low sponge ranking compared to the other cities, with only Sydney scoring lower - both in terms of its green-blue area and overall sponge ranking.

City Dashboard

London Analysis

Ranking 6th

Sponge Percentage 22%

Permeable Surfaces 31% Green / Blue

Soil characteristics

Moderately-high runoff potential

<50% Sand

20-40% Clay

Click onto the map to expand

Montreal

Montreal

Area surveyed

Montreal is the second most populous city in Canada with nearly 1.8 million residents. The city is centered on the Island of Montreal, flanked to the south by the Saint Lawrence River and to north by the Prairies River.

The study area includes approximately 150km^2 of the Island of Montreal, spanning from the Saint Lawrence River in the south, including Verdun and the Southwest Borough; the Olympic Stadium in the East; the Trans-Canada Highway in the North; and the CN Rail intermodal yard in the West. Within this area is notably Mont Royal Park and the Central Business District. The area is representative of Montreal as a whole with a variety of land uses and urban typologies, including high-, medium-, and low-density housing, medium- and high-density office space, major road arteries, urban parks and green space, industrial sectors, and more.

Flood risk

Montreal is susceptible to flooding during heavy rainfall events in low-lying areas with high impermeability and aging infrastructure. Along its shorelines, Montreal has been particularly vulnerable to springtime flooding in recent years, with thousands of people displaced and millions of dollars in damages to homes and businesses.

Climate change projections in the Montreal region include both more total rain and more frequent high-intensity events, higher average temperatures, and longer heatwaves in the summer. In addition, challenges posed by winter snow and ice management in Montreal's northern climate increase vulnerability to warm winter weather events which bring heavy rainfall on top of snow and ice. These events are proving to be particularly catastrophic and are expected to become more frequent.

Sponge ranking

Montreal came 4th in our 'sponge ranking', just ahead of Shanghai and behind Singapore, Mumbai and New York City which were joint 3rd.

As the data suggests, the study area's prominence of impervious surfaces and buildings will have had a considerable impact on its 'sponginess'; however, one fifth of the land surveyed also provided tree coverage. Montreal scored lower than other cities because its study area had fewer green-blue areas at 36% compared to Auckland, Nairobi and Mumbai which have 50%, 52% and 45% respectively.

The city has a mid-ranking soil type, similar to Auckland, Shanghai, London and Sydney. However its soil was assessed as being slightly more impermeable, meaning less runoff, compared to the likes of Singapore. It should also be noted that cold climate impacts on flood risk are not directly accounted for in terms of 'sponginess'.

City Dashboard

Montreal Analysis

Ranking 4th

Sponge Percentage
29%

Permeable Surfaces
36%
Green / Blue

Soil characteristics

Moderately-high runoff potential

<50%
Sand

20-40%
Clay

Click onto the map to expand

Mumbai

Mumbai

Area surveyed

Mumbai is the ninth most populated city in the world, with a population of over 20.6 million and one of the most densely populated. There are distinct differences in the quantity of greenery around the city, closely correlated to an area's wealth. The more sparsely populated areas which include tower blocks and medium rise residential areas have small parkland areas with trees aplenty. Greenery in these areas is well integrated with housing and commercial builds. However, in high-density, low-rise informal settlements there is very little to no greenery and subsequently the residents will be unable to draw on the benefits provided by green infrastructure.

Flood risk

Mumbai is likely to be hit by many more incidents of extreme weather, and indeed endures a monsoon season between June and September, bringing most of the yearly rainfall quantities.

Floods often cause devastation. In 2005, the Maharashtra floods led to the deaths of more than 1,000 people, caused by the 8th heaviest-ever recorded 24-hour rainfall figure of 944mm.

Torrential rainfall continued for a week and the floods caused a direct loss of about 5.50 billion rupees (€80 million or US$100 million).

In late August 2017, Mumbai recorded 468mm of rainfall in 12 hours and 21 people died. Transport systems were unavailable through parts of the city as trains and roadways were shut. Power was shut off from various parts of the city to prevent electrocution.

In July 2021, Mumbai International Airport recorded 235mm of rain in 24 hours. The heavy rainfall led to landslides and flooding, causing the death of at least 20 people.

Sponge ranking

Mumbai was joint third in our 'sponge ranking', alongside Singapore and New York. However, as the data suggests within the study area, the city benefits from a large quantity of green infrastructure, particularly tree cover. This is driven by large areas of woodland to the north-east but more interestingly a large quantity of trees interspersed around buildings that are spread across the whole study area. This integration of green infrastructure across the urban areas helps give the city some resilience to storms but also urban heat island effects.

However, a high proportion of the study area also featured high-density development with almost no green space, and consequently, the green infrastructure is not providing stormwater management or other benefits in these areas.

The city's sponge ranking was achieved by several factors working together. Firstly, it was hindered by having the joint-least permeable soil type of the other cities – meaning less water can be absorbed and subsequently runs off onto adjacent areas. However, the high runoff potential of the soil type is counteracted by the city's high percentage of permeable surfaces, having the joint third highest percentage of green-blue areas in the cities studied.

The type of permeable surface also plays a part. The study assessed that there is a greater amount of tree coverage than grass or other green across the city: comparable to the tree coverage of Singapore and New York.

City Dashboard

Mumbai Analysis

Ranking 3rd

Sponge Percentage

30%

Permeable Surfaces

45%

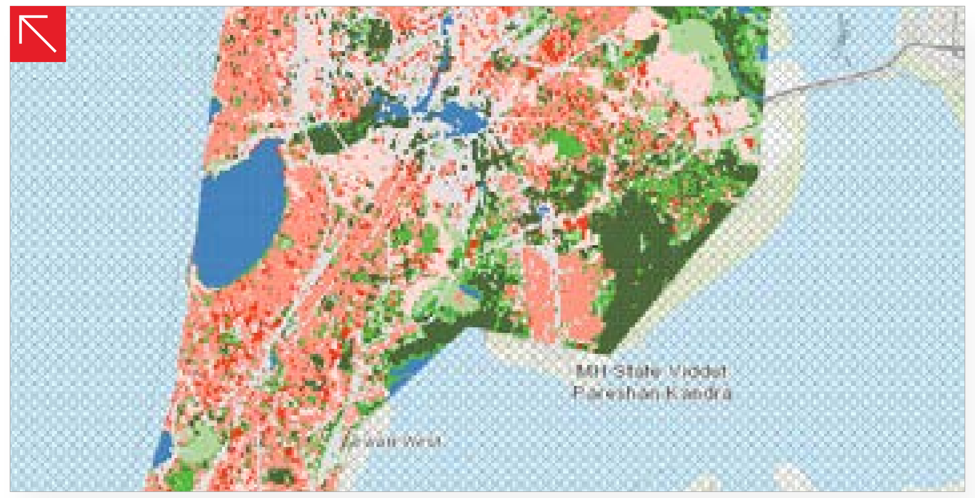
Green / Blue

Soil characteristics

High runoff potential

<50%
Sand

20-40%
Clay



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Nairobi

Nairobi

Area surveyed

Kenya's capital Nairobi is an inland city elevated at 1,795m above sea level. The long rainy season runs between March and May with a shorter rainy season between October and December. The yearly average rainfall is 1,061mm while temperature ranges between 10-29 degrees Celsius. The main types of soils are black cotton and red soils that form patches in different parts of the city.

Whilst the city has large areas of national and public parks within the study area, it is also dominated by low rise residential and urban backyard typologies. Both of these contribute significantly to the area of blue-green infrastructure across the city.

The other dominant typology is 'dense low-rise urban' which was assessed as having no green-blue areas within it. Subsequently the residents will be negatively impacted as a result, unable to draw on the benefits provided by green infrastructure.

Nairobi was the only city of those studied not to have a major water body within. The Nairobi Dam was empty at the time the study was undertaken.

Flood risk

It has become the norm to expect flooding in Nairobi when it rains, leading to submerged slums.

With most climate models predicting heavier rainfall and flooding as temperatures rise in future years, the city faces a huge challenge ahead.

In April 2016, inhabitants of Nairobi were caught up in flash floods after a storm brought heavy rainfall that lasted for nearly 3 hours. Some streets were under a metre of water, causing trees to be uprooted and damage to buildings and vehicles. During a previous event in May 2015, 10 people died after a building collapsed due to floods.

Recently Kenya saw its population being displaced across the country due to floods. In May 2021 floods struck Nairobi which led to the death of four people and considerable material damages in parts of the capital.

Sponge ranking

Nairobi came second in our sponge ranking, behind Auckland and ahead of Singapore. As the data within the study area suggests, the city benefits from a large quantity of green infrastructure, particularly grasslands. This is driven by parkland as well as urban backyards spread across the study area.

However, a high proportion of the study area also featured high-density development with almost no green space, and consequently, the green infrastructure is not providing stormwater management or other benefits in these areas.

The city's sponge ranking score was influenced by two key factors. Firstly, it was negatively affected by having the joint-least permeable soil type in the snapshot – meaning less water can be absorbed and subsequently runs off onto adjacent areas. However, the high runoff potential of the soil type is counteracted by the city's high percentage of permeable surfaces. It has the highest percentage of blue-green areas in all the cities studied, the next highest being Auckland.

City Dashboard

Nairobi Analysis

Ranking 2nd

Sponge Percentage

34%

Permeable Surfaces

52%

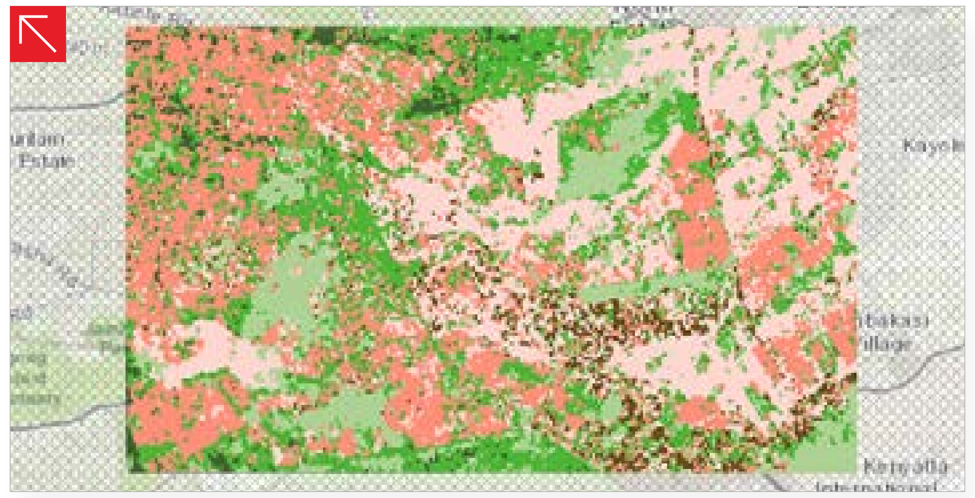
Green / Blue

Soil characteristics

High runoff potential

<50% Sand

>40% Clay



Click onto the map to expand


New York City

New York City

Area surveyed

New York City (NYC) is a densely populated urban area home to 8.4 million people. The low-lying coastal city is bound by the Hudson River and the East River. The 150 square kilometre area of NYC surveyed included Manhattan – taking in major landmarks such as Central Park, but also the suburban expanses in the Bronx to the north and a small section of Queens to the east. It included a mix of dense urban high-rise areas through to urban parks, with medium density urban areas making up the greatest proportion.

Flood risk

NYC is facing an increasing threat of flash floods and events which will see far greater levels of rainfall hit within a short space of time. It has been predicted that the city will face an increased average level of rainfall from 4 to 11% and rising sea levels of 280mm to 530mm by the 2050s. The number of most intense hurricanes across the North Atlantic Basin is also expected to increase, testing the resilience of the city. In 2021 Tropical Storm Elsa left New York facing double the amount of precipitation expected for the month of July in just a few days, which lead to pluvial flooding across the city.

Sponge ranking

NYC came joint third in our 'sponge ranking' though in fact, London and Shanghai came ahead of it in terms of percentage of hard surface land. Compared to other cities surveyed, such as Auckland, the amount of green and blue infrastructure across the study area is less evenly spread. In the Bronx, to the north, there are more parks and larger green areas, with a significantly higher number of trees interspersed around buildings. But to the south of Manhattan island, with the exception of Central Park, there is much less vegetation with the streets much more heavily urbanized.

The city's score was achieved in part by its permeable soil type – meaning more water can be absorbed and not run straight off it. However soil type alone is not enough; these need to be accessed through permeable surfaces and New York has a good percentage, roughly mid-table compared to the other cities.

The type of permeable surface also plays a part. The study assessed that, of the green surfaces in New York, there is a greater amount of tree coverage than grass or other green across the city. Comparable to similar quantity of tree coverage in Singapore. This is important for the calculations as trees have a more significant on intercepting rainfall than grass, for example.

City Dashboard

New York City Analysis

Ranking 3rd

Sponge Percentage

30%

Permeable Surfaces

39%

Green / Blue

Soil characteristics

Moderately-low runoff potential

40-70%

Sand

<10%

Clay

Click onto the map to expand

Shanghai

Shanghai

Area surveyed

Shanghai is the third most populated city in the world, with a population of over 24.2 million. The city is dominated by the Huangpu River, which has multiple tributaries, and divides the city into two halves.

The study area includes the Wennan and Dianbei districts (west of Huangpu river) and part of the Pudong district (east of Huangpu river). From a green infrastructure perspective, there are green areas throughout the city, but the city gets its largest proportions of green-blue infrastructure from urban parks which were assessed as being more prevalent to the east of the study area. To the west, the study area features a larger proportion of urban typologies with fewer green-blue areas. High rise and medium density residential typologies dominate the city's make up, although both do feature reasonable proportions of permeable surfaces. Our assessment indicates that the current green infrastructure within the city is unlikely to be well integrated to help manage stormwater.

Flood risk

Shanghai is particularly susceptible to extreme weather; as recently as September 2021, schools and businesses all over the city were closed as a strong typhoon approached.

The Chinese government implemented defences along the river to protect its major metropolitan areas during the 20th century, as it is estimated that major deforestation work removed many of the natural flood barriers and absorbing materials.

From a climate change perspective, the densely populated areas of Shanghai are greatly at risk and it is estimated that a 3 degrees Celsius increase in sea temperatures would lead to a displacement of 14 million people.

In addition, Shanghai's expansive reclamation of land could cause areas to sink given the soft nature of the land they are built upon.

It is estimated that a 1 in 100-year flood event could have devastating impacts on Shanghai, which was calculated in 2012 to be one of the most vulnerable major cities to flooding.

The scale of the damage is exacerbated when considering the cities global economic significance as the China's financial capital and one of the busiest shipping ports in the world.

Sponge ranking

Shanghai came fifth in our 'sponge ranking', just behind Mumbai. However, as the data suggests within the study area, the city scored lower because it has fewer green-blue areas at just 33% compared to Mumbai which has 45%.

The city only has a mid-ranking soil type of the cities in the snapshot, similar to Auckland, Singapore, London and Sydney. Its soil was assessed as being slightly more permeable, meaning less water runs off than Mumbai and Nairobi. However, it is the lower quantity of blue-green area that resulted in Shanghai scoring lower than Mumbai.

City Dashboard

Shanghai Analysis

Ranking: 5th

Sponge Percentage: 28%

Permeable Surfaces: 33% Green / Blue

Soil characteristics

Moderately-high runoff potential

<50% Sand

20-40% Clay

Click onto the map to expand


Singapore

Singapore

Area surveyed

Singapore is a large city of approximately 5.5m people. The city benefits from a high quantity and quality of green areas which are integrated throughout the urban areas and also contains many large parklands and open green areas. The majority of residents with houses have the benefit of a private garden. Higher density settlements and high-rise buildings are located close to green spaces and trees are in abundance.

Over the past 50 years, Singapore invested heavily in its drainage system and developed blue-green infrastructure across the city to minimise flooding.

Flood risk

With a tropical rainforest climate, the coastal low-lying city has an average monthly rainfall of over 176mm. Higher rainfall occurs from November to January, with the driest month being February.

The contrast between the wet months and dry months in Singapore is predicted to become more pronounced, with both intensity and frequency of heavy rainfall events expected as the world gets warmer.

Flash floods occurred on 14 days in 2017, up from 10 in 2016 and six in 2015. Singapore has also experienced several major floods in recent years that have resulted in destruction to assets and property.

Sponge ranking

Singapore ranked joint third in the study, alongside Mumbai and New York.

The data suggests that within the study area, the city benefits from a large quantity of green infrastructure, particularly tree cover. This is driven by areas of woodland to the north as well as many of the roads or highways incorporating green infrastructure.

The study assessed that there is a greater amount of tree coverage than grass or other green across the city, comparable to the tree coverage of Mumbai and New York. This is important for the calculations as trees have a larger effect on intercepting rainfall than grass or other permeable surfaces.

The city has a mid-ranking soil type, similar to Auckland, Shanghai, London and Sydney. However, its soil was assessed as being slightly more permeable, meaning less water runs-off, when compared to Mumbai and Nairobi.

City Dashboard

Singapore Analysis

Ranking 3rd

Sponge Percentage 30%

Permeable Surfaces 45% Green / Blue

Soil characteristics

Moderately-high runoff potential

<60% Sand

20-50% Clay

Click onto the map to expand

Sydney

Sydney

Area surveyed

Sydney is a coastal city with an annual average rainfall of 1,147mm which has been historically relatively uniform throughout the year, although recently the rainfall has been more summer dominant.

Developed around its harbour, Sydney has high amenity benefits and biodiversity coming from blue infrastructure, and it does have some parkland space particularly to the east. However, further inland to the west, the study area features a large proportion of high rise and medium density residential typologies with lower quantities of permeable surfaces. The study assessed that the current green infrastructure within the city is unlikely to be well integrated to help manage storm water.

Flood risk

In February 2020, the Sydney metropolitan experienced its heaviest rain in 30 years, over three days. The city recorded around 391.6 mm of rain within those three days, which is more than three times the average rainfall for February.

Warragamba Dam reached as close to 70% capacity after the deluge, a week earlier the dam was only at 42% after one of the driest years on record and this event put 10 million Australians under a severe flood warning, with floods forecast to affect most states excluding Western Australia. At least 18,000 people were evacuated from New South Wales.

In March 2021, the city was again hit by a 1 in 50-year event as days of heavy downpours caused fluvial flooding and required military assistance for search and rescue. This rainfall event caused Warragamba Dam to spill, the first significant overflow of the reservoir since 1990 and widespread flooding along the east coast of Australia.

Scientists fear localised flooding could occur almost every week by 2050 due to human-caused sea level rises, according to Bureau of Meteorology.

Wet weather overflow from sewage mains into stormwater mains is also a frequent occurrence leading to pollution of the city's beaches and harbours and the majority of the city's stormwater network is only designed to accommodate a 1 in 2-year storm event.

Sponge ranking

With about 76% of the surface area of the city assessed as being impervious or covered by buildings, it had the highest percentage of hard surface land of the cities analysed. This is the main reason that the city scores lowest in the rankings.

Many of the natural creeks and river throughout the city have been concrete lined to form more formal stormwater channels.

The soil type is assessed as very similar to Auckland's in terms of permeability but the larger quantity of blue-green infrastructure in Auckland is what has resulted in the difference in two cities' rankings in this study. An increase in the city's percentage of blue-green areas would help to increase its score in the rankings.

City Dashboard

Sydney Analysis

Ranking 7th

Sponge Percentage

18%

Permeable Surfaces

24%

Green / Blue

Soil characteristics

Moderately-high runoff potential

>60%
Sand

10-30%
Clay

Click onto the map to expand


Toronto

Toronto

Area surveyed

Toronto is home to over 2.9 million residents, placing the city as the largest in Canada and the fourth most populated in North America. The city is bounded by Lake Ontario to the south and the downtown area is bordered by two major watercourses, the Don and Humber Rivers, to the east and west, respectively.

The study area includes approximately 150km^2 of the city including the high-density downtown core, a mix of medium- and low-density housing, and major urban parks. Notable areas and neighbourhoods include the Union Station Rail Corridor and Gardiner Expressway, High Park, the Lake Ontario Waterfront, Port Lands Redevelopment Area, and sections of the City's ravine system including the Lower Don Valley and Humber River Valley. The downtown core and associated districts are dominated by areas of high to medium density urban typologies, both having relatively low proportions of green-blue areas. Other areas, like Midtown, comprise of a larger variety of land uses, including low-density housing, major road arteries, parks and green spaces, cemeteries, and industrial sectors.

Flood risk

Toronto is a growing city in the midst of a densification and development boom. The city is undergoing a period of intense transit expansion and currently leads North America in the number of construction cranes in operation. However, most of the city's modern development would not have been possible without nearly a century of work from 1850 onwards to bury and culvert most of the city's natural watercourses, now known as "lost rivers." These underground features are a reminder that water is meant to flow naturally into the ground, feeding rivers and streams that once used to be visible. Flooding is common today near many of these lost rivers, as well as in areas near the city's floodplains, and meanwhile Toronto's rainfall is becoming increasingly intense. There have been over six 100-year events in the past 20 years, and it is predicted that with climate change these extreme weather events will become more frequent, leading to a greater risk of flooding, infrastructure damage, and impacting community wellbeing.

Sponge ranking

Toronto came joint 3rd in our "sponge ranking," just ahead of Montreal and tied with New York City, Singapore, and Mumbai. Over one quarter (29%) of the land analyzed in Toronto is covered in trees. Noticeably, much of the study area's trees were in the Don Valley and its connected ravine network, to the east, somewhat removed from buildings or the city's most densely populated areas. Toronto's ravines are naturally spongy green spaces which provide co-benefits such as improving air quality, protecting biodiversity, and enhancing wellbeing.

However, much of the upstream catchment area in the Don and Humber River watersheds is impervious, particularly along the right-of-way. Sponginess offered by green infrastructure could provide a much-needed layer of retention to Toronto's water management strategy that, to this day, has relied heavily on conventional grey infrastructure such as tanks and sewage interceptor tunnels. Nature-based solutions not only provide flood relief, but also socio-economic and environmental benefits including greater respite from urban heat events, community education and recreation, increased property value, and restoration of urban wildlife.

City Dashboard

Toronto Analysis

Ranking 3rd

Sponge Percentage 30%

Permeable Surfaces 39% Green / Blue

Soil characteristics

Moderately-high runoff potential

<50% Sand

20-40% Clay

Click onto the map to expand

Digital technology as an enabler of nature-based solutions

Nature-based solutions have previously been seen as more difficult to implement and prohibitively expensive. But advanced digital tools have been a game changer.

In our recent report with the World Economic Forum, BiodiverCities by 2030: Transforming Cities' Relationship with Nature, we highlighted that nature-based solutions are on average 50% more cost-effective than man-made alternatives and deliver 28% more added value.

Digital tools are transforming our ability to assess cities' preparedness for future climate risks and identify opportunities for improvement. Thanks to the power of AI and machine-learning, we can now quantify the case for nature-based solutions; better understand a city's natural ability and how to enhance it.

Projects around the world from Shanghai, China to Mansfield, UK - are showing what is possible and now is the time to accelerate their adoption on global scale.

Terrain tool

Arup's Terrain tool is being used around the world to help planners and authorities understand how land is being used, as well as to conduct global surveys such as the Global Sponge Cities Snapshot, which assesses the natural ability of major global cities to absorb water and mitigate urban flooding problems based on their green and blue spaces.

Terrain harnesses the power of data analytics, machine learning and automation to digest large quantities of data and satellite imagery. It recognises patterns, producing detailed land use maps and accurately calculating a region's percentage coverage of different categories of land type – such as grass, trees, hard paved impervious land, buildings, and water.

This automates the traditionally time-consuming task of deciphering a city's typology: Terrain is x5 quicker than a manual approach, able to analyse 20,000m² of land data per second. The technology is also highly accurate and can even distinguish between a tree nursery and a forest.

Shanghai – urban drainage masterplanning

An example of this in practice is our work in Shanghai. The Shanghai metropolis covers 640 square kilometres and has a population of 15 million - a number that has tripled since 1990. As its impermeable concrete spaces have grown and green spaces decreased, stormwater runoff across the city has increased. On top of this, the existing drainage system was already challenged in both old and newly developed areas.

Shanghai's risk of city flooding and river pollution was an urgent issue: the city needed advanced yet implementable strategies. Arup won an international competition – organised by the Shanghai Water Authority – to provide a stormwater masterplan for the city. We used remote sensing tools to scan Greater Shanghai and used our Terrain machine learning tool to interpret the images and categorise the entire area into 12 categories of flooding protection required.

This analysis, alongside a review of the previous drainage masterplan and a study of relevant cases across the globe, gave us the insight to devise a targeted water management approach. Instead of focusing solely on drainage, we proposed a visionary 'blue, green and grey' approach to support an integrated water cycle within the city. Based on the Arup-developed 'design with water' framework, our urban flooding model found opportunities to use blue infrastructure. This was the first-ever model to integrate the river and drainage network in Shanghai. An additional enabling factor for this masterplan was improved governance across the water system. Find out more.

Will Cavendish
Global Digital Services Leader

Digital technology as an enabler of nature-based solutions

Mansfield – showing the wider benefits of nature-based solutions

Our project in Mansfield, UK, shows how Terrain can help quantify the benefits of nature-based solutions. Arup undertook a rapid assessment of the potential of different land uses in Mansfield to accommodate nature-based solutions and mitigate surface water flood risk. We then carried out a cost-benefit analysis of the different potential scenarios, which included the assessment and valuation of wider benefits associated with the implementation of nature-based solutions.

We calculated that an additional £6 million investment to establish a green stormwater management solution would result in wider benefits of more than £22 million. On top of improved resilience to floods, the benefits hit a variety of stakeholders: health benefits for citizens due to changes in the living environment; increased local, government and business revenues because of stimulated local economic activity and upskilling in green economy jobs; and improved human health and happiness thanks to improved amenities.

Based on our analysis, the Office of Water Services in England and Wales allocated £75.7 million to Severn Trent to build sustainable green infrastructure and resilient communities in Mansfield.

Tirana Orbital Forest – securing access to funding

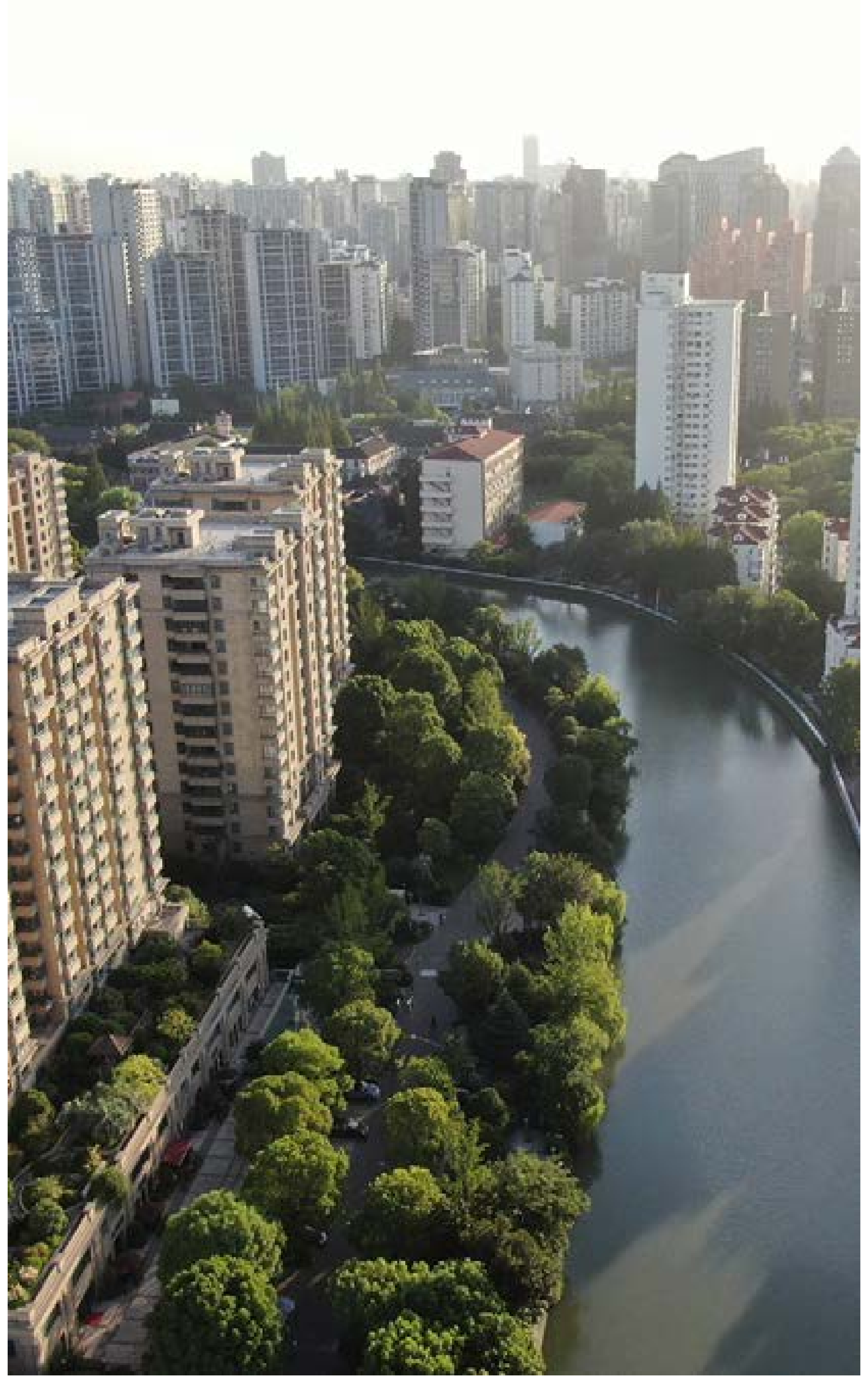
In Tirana, Terrain was used to secure access to vital funding for a proposal by its Mayor. The Tirana Orbital Forest is a proposed ring around the urban perimeter of the city with a mix of forests, shrubland, agricultural land and recreational areas – a large-scale, nature-based solution that is intended to put a brake on urban sprawl, reconnect the citizens with nature, clean the air and address urban heat effects.

Arup is supporting this vision by using Terrain to assess the environmental and economic benefits of different forest options and scenarios the city could adopt. We are working with the European Bank for Reconstruction and Development (EBRD) to develop a financial and technical feasibility study for the Orbital Forest, taking into account the wide-ranging indirect economic benefits – from health improvements for residents, to a new leisure business ecosystem. The project is a first of its kind for the Bank – and will seek to demonstrate that holistic, nature-based solutions can be as effective as grey infrastructure to address environmental challenges and deliver net economic benefits worth investing in. Find out more.

Looking forward

As cities increasingly face extreme flood events due to the impact of climate change, we need to look to nature-based solutions to help cities become more resilient. But for many, the adoption of nature-based planning will require a significant transition - and leaders may struggle to prioritise.

Now, digital mapping can facilitate more informed, faster decision-making around nature-based urban solutions. We hope that these tools will help city leaders better understand the complexity of city ecosystems, provide clarity on what is possible, and convince them of the powerfully positive impact of nature-based infrastructure.



Shanghai Urban Drainage Masterplanning
Shanghai Metropolis covers 640 square kilometres. We used remote sensing tools to scan the area then used our Terrain AI land use analysis tool to interpret the images and categorise the entire area into 12 categories of flooding protection required.

Future recommendations

Bringing nature-based solutions to life

Nature already has the answers. We just need to listen. Nature-based solutions can be affordable and scalable; they have a powerful role to play in decarbonising the built environment.

Working in tune with natural systems is critical to responding to climate change positively. Nature-based solutions is a term used to describe a diverse range of techniques that increase our resilience to climate impacts - such as overheating, flooding, and more frequent and intense storms to the overuse of natural resources - whilst simultaneously supporting the regeneration of ecosystems.

An evolving set of methods, nature-based solutions represent an essential step forward beyond ‘hard’ approaches traditionally deployed by built environment practitioners.

In this report we have focused on harnessing nature to improve flood risk management. Increasing concentrations of atmospheric greenhouse gases means that global climate systems have been seriously disrupted. In many locations this means more extreme rainfall and more frequent flooding. Climate scientists have confirmed that flooding will continue to intensify over coming decades. Relying solely on physically constructed barriers to protect us from flooding is no longer the best approach.

Each environment is unique, and designs include features best suited to the site, from green spaces, rainwater gardens and permeable paving to rainwater harvesting and retention ponds. Combining traditional grey infrastructure approaches with these nature-based solutions can provide infrastructure solutions that transform a neighbourhood’s capacity to flood resilience, while simultaneously integrating more green space to the urban fabric.

Strategies to improve the sponginess of cities should be based on four core principles:

1. Integrated: working at basin-scale, taking into consideration existing plans and strategies across multiple different city departments, including city strategies and flooding, water-management, infrastructure and development plans.
2. Systems-led: interventions must be implemented across the interconnected systems that make up a city’s water environment. Strategies should be optimised across four systems:
   - Governance: a critical over-arching system for strategy development and implementation involving no-build solutions such as enforcing sponge city planning guidance and design standards, regulation, incentivisation, information sharing and collaboration
   - Green infrastructure: maximise above-ground interventions to increase storage, improve water quality and reduce flooding at or near to source, primarily using nature-based solutions. These include parkland, meadows, recreation areas, street trees, green roofs and walls, and sustainable urban drainage systems
   - Blue infrastructure: the network of hydraulically controlled urban rivers and canals including associated flood defences, pumping stations and tidal controls. This also includes ponds and lakes. Modelling these in an integrated way can maximise storage and minimise flooding.
   - Grey infrastructure: underground drainage infrastructure and pumps, storage and treatment. By focusing on governance and blue and green infrastructure, the need for residual grey infrastructure can be significantly reduced
3. Adaptive: interventions aligned with an adaptive management approach that provides flexibility to address future uncertainty and new insight, avoiding inefficiency and unnecessary spending and delivering better outcomes over time. This could include phased strategies that looks at small interventions that can be delivered quickly alongside planning large infrastructure investments.
4. SMART: Strategies should be based on robust data science and smart integrated models which optimise the existing infrastructure, allow sophisticated future planning scenarios and support monitoring programmes the performance of solutions based on local conditions.

ARUP