Blue-Green Infrastructure:
A new business case for New York City

October 2023

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Cover image ▲
Rendering of proposed Cloudburst Basketball
court in Clinton Houses, New York.
Image credit: Ramboll

Images to the right ▶
Different angles of Verdensparken, Oslo (Norway).
Image credit: Ramboll

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BY
DESIGN

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First Edition

Published: October 2023

Disclaimer: All site-specific solutions shown in this report are to be understood as part of a broad study for the purpose of upscaling and extrapolating values, and not as planned designs for these locations.

Verdensparken, Oslo (Norway)
Image credit: Ramboll
Ramboll's contributions to Verdensparken encompass terrain adaptation and cloudburst management. To ensure protection against flooding, a large rain is implemented, effectively draining surface water while creating a vibrant expanse of green perennials and grasses. Additionally, the playground incorporates recycled cobblestones and flood protection blocks.

Glossary

Benefit-Cost Analysis (BCA): A method to assess the wider societal and economic benefits and costs of a project.

Benefit-Cost Ratio (BCR): Benefits divided by costs equal the benefit-cost ratio. If the Benefit-Cost Ratio is equal to or greater than 1.0, then the project is cost-effective and applicable for funding through FEMA**.**

BGI Network: A flexible and multi-functional system of BGI. A network of natural and semi-natural spaces strategically designed within urban areas to provide multiple ecological, social, and economic benefits.

Blue-Green Infrastructure (BGI): Stormwater management practices that connect urban hydrological functions (blue) with vegetation systems (green) and community priorities (multi-functional). BGI offers valuable solutions for urban areas facing the challenges of climate change and reduces the need for traditional gray infrastructure. Multi-functional BGI co-designed with communities generates social, economic, and environmental value. BGI is a subset of NBS.

Business case: Used interchangeably with Benefit-Cost Analysis

Capital Expenses (CAPEX): The monetary costs associated with the acquisition, and/or construction of infrastructure assets.

Cloudburst: A sudden, heavy downpour where a large amount of rain falls in a short amount of time. Cloudburst events can overwhelm storm sewers causing flooding, property damage, disruptions to critical infrastructure, and pollution to waterways. "Cloudburst" is often used interchangeably with other terms such as “extreme rainstorm,” “extreme rain event,” or extreme precipitation.

Cloudburst Master plan: Another term for a BGI Network. It is a catchment-based strategic plan designed to manage and reduce the impacts of sudden, heavy rainfall (also known as cloudbursts) in urban areas.

Co-Benefits: Co-benefits describes the added benefits of BGI, in addition to the primary purpose of flood risk reduction and/or pollution prevention. Co-benefits of BGI can include improved air quality, recreational value, physical activity, micro-climate, traffic safety, biodiversity, and noise reduction.

Conveyance: Stormwater facilities that are intended to transport water in a controlled way to outlets, treatment facilities or floodable detention sites. Examples include drainage pipes, roadways, and bioswales.

Detention: Stormwater facilities that are used to temporarily store water in a controlled manner during cloudburst events. Once the storm passes and the drainage system empties, detention facilities drain into the existing sewer network. Examples include bioswales, sunken athletic fields, and sunken parking lots.

Design storm: A design storm is a defined rain event including potential climate factors, whose Intensity, Duration, and Frequency (IDF) are selected as a desired level of protection (Return Period) and design criteria for resilience planning.

Discount rate: Discounting is a method used to compare benefits and costs that occur at different times. It involves converting the value of future benefits and costs to their equivalent present values at the start of the project’s lifespan. For federally funded mitigation projects, a discount rate of 7% is mandated, as determined by the U.S. Office of Management and Budget (OMB).

The Federal Emergency Management Agency (FEMA): An agency under the Department of Homeland Security tasked with coordinating within the federal government to make sure America is equipped to prepare for and respond to disasters.

Green Infrastructure: Measures that use plant or soil systems, permeable surfaces, and landscaping to store, infiltrate, or absorb stormwater and reduce flows to sewer systems and waterways.

Nature-Based Solutions (NBS): Nature-Based Solutions are broad strategies that leverage the inherent qualities of nature to address various societal challenges, including those related to urbanization, climate change, and environmental degradation. NBS encompass a wide range of approaches that utilize nature or natural processes to provide benefits to both the environment and human well-being.

Operating Expenses (OPEX): Ongoing costs for maintaining assets and infrastructure.

Return period: The return period defines how frequently and how intense rain events of the same magnitude will occur in a specific location. For example, a ‘10-year event’ would have a 10 % chance to occur every year. This does not guarantee that this rain event would occur once every 10 years but would instead provide the probability that the storm would occur in a given year.

Service level: The stormwater service level describes the expected or designed capacity of the storm sewer system. Service Levels are often expressed using a Return Period, such as a 5-year rain event. When the service level is exceeded the stormwater drainage system may overflow and cause flooding and/or pollution.

Foreword

On September 29th, 2023 New York City was forced to a standstill as streets, homes, subways, and businesses were flooded from heavy rainfall. The flooding adds to a growing list of named and unnamed extreme flood events that have left communities with enduring physical and mental trauma. Each event has confirmed the grim reality that scientists and residents have been warning about for decades: climate change is here, and storms that feel extreme now will only become more frequent and more intense.

The New York City Panel on Climate Change (NPCC) anticipates that by the end of the century, the city could experience as much as 25% more annual rainfall than today, and a 50% increase in the number of days with more than one inch of rain[1]. Events like these will continue to place pressure on an already stressed sewer system in NYC.

In May of 2023, New York City announced the investment of $3.5 billion in green infrastructure and property acquisition to address flooding, more than half of which has already been committed. However, the City's infrastructure is still far from being able to handle recod-breaking events like September 29th, Hurricane Ida, Hurricane Henri, or even moderate rain events that rarely make news headlines.

NYC's toolkit for addressing the rising frequency and intensity of heavy rainfall is expanding. Cities worldwide, such as Copenhagen and Hoboken, are setting an example by increasingly turning to blue-green infrastructure to capture more runoff and gradually convey it to sewers, buying time for them to catch up to the intensity of the storm.

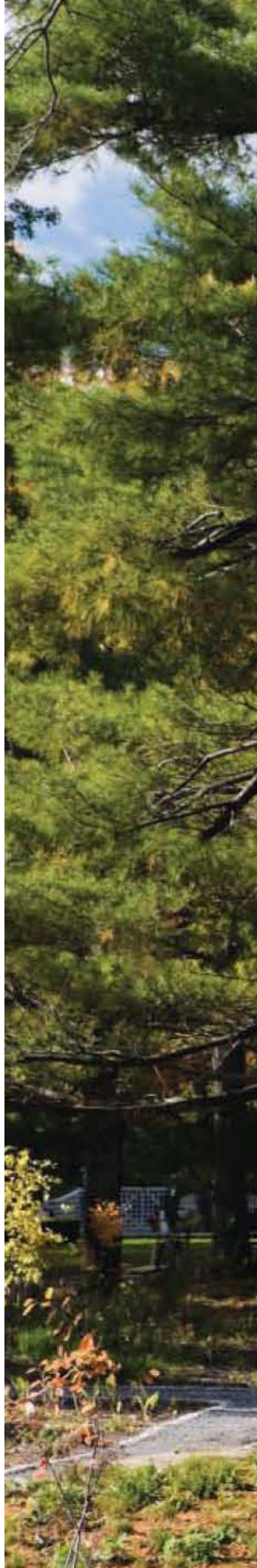
To initiate a new thinking around stormwater management, the New York City Department of Environmental Protection (DEP) entered into a partnership with the City of Copenhagen. As part of this partnership the Copenhagen "Cloudburst Management" approach was tested in a NYC setting. This resulted in the "Cloudburst Resiliency Planning Study" published by DEP in 2017,[2] prepared by Ramboll which marked the beginning of the DEP Cloudburst Program.

In response to the increasing frequency of flood events in NYC, Rebuild by Design released the report "Towards a Rainproof NYC: Turning the Concrete Jungle into a Sponge." The Rainproof NYC strategy demonstrates how the city could adapt to increasing precipitationthrough systematically applying blue-green, multi-benefit solutions, while creating co-benefits – such as cleaning our air and improving physical and mental health – for New Yorkers' lives every day.

In 2022 Rebuild by Design partnered with Ramboll to further advance the citywide implementation of multi-purpose Blue-Green Infrastructure in NYC. The result of this partnership is the citywide business case for multi-purpose Blue-Green Infrastructure and concrete recommendations for further actions presented in this report. Enjoy!

Rebuild by Design

Ramboll



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[1] Mayor's Office of Resiliency, "NYC Stormwater Resiliency Plan", May 2021.

[2] https://www1.nyc.gov/assets/dep/downloads/pdf/climate-resiliency/nyc-cloudburst-study.pdf

Queens Botanical Garden, Queens (New York)
Image credit: Ramboll
Ramboll Studio Dreiseitl teamed with Chicago-based plant experts Conservation Design Forum and local architects BKSK to develop a people inspired master plan. The master plan accommodates 0% run-off of stormwater for a 1 in 100 storm. Attractive stormwater detailing, such as 6000 sf green roof on the new administration building and the reuse of storm water run-off for cultural water features and irrigation, give the garden a unique, water related character. Gray water is captured, cleansed and reused for low-contact irrigation.

Executive summary

The project in short

BACKGROUND

Rebuild by Design and Ramboll have formed a partnership to further advance the city-wide implementation of multi-purpose Blue-Green Infrastructure in NYC.

The partnership centers around the question:

How economically feasible is a citywide, multi-functional, Blue-Green Infrastructure master plan for inland flood resilience in New York City?

To meaningfully answer this question, Ramboll has conducted city-wide flood and climate-risk modeling for current and future climate conditions. Using representative case areas across all five boroughs, BGI master plans have been developed and upscaled city-wide. A Benefit-Cost Analysis (BCA) has been performed, incorporating costs, reduced damages, and added socio-economic value to illustrate the feasibility of these factors across all of New York City.

FINDINGS

The citywide analysis and benefit-cost ratio indicate that:

1. Nature-based, multi-functional BGI provides a positive benefit-cost ratio for the majority of neighborhoods in NYC.
2. Co-benefits are at the heart of the new business case for inland flood resilience in NYC.
3. BGI in NYC is most cost-efficient and provides more co-benefits when implemented in open space areas.
4. For every $1 invested in a BGI Network design to the 10-year storm in 2050 New York City makes $2 in return.

RECOMMENDATIONS

The findings from this study are based on a spatial upscaling. We recommend locally tailored analysis to strengthen the contextual aspects of these conclusions. Additionally, we recommend the following 5 steps to advance cloudburst resilience in New York City:

- Document BGI maintenance: evaluate and document models for co-financing, and maintaining BGI in order to develop maintenance manuals for NYC.
- Prioritize co-benefits: develop catalog of next generation BGI typologies for NYC that maximize community benefits.
- Include social vulnerability: ensure prioritization of the most socially vulnerable populations in the Benefit-Cost Analysis.
- Define citywide protection level: define methodology for levels of protection for NYC, including acceptable level of risk, and design return periods for extreme rainfalls.
- Prioritize cloudburst pathway: develop transparent pathways for prioritization of catchments/neighborhoods in cloudburst program.

Citywide inland flood resilience business case

Why?

Why a citywide inland flood resilience business case?

Several studies indicate that NOAAs 1-in-100 year flood (100 year return period) already now can be expected much more often, and for NYC most likely between 1-in-10 and 1-in-20.

Across the world cities are facing the triple challenge of aging underground stormwater infrastructure combined with increased expectations to service level, and the prospect of more frequent high-intensity rain events and more rain in general as a result of climate change.

Traditional (gray) stormwater infrastructure — discharging rainwater into pipes — is no longer an adequate solution in the context of dense urban environments, especially as climate change is projected to increase the frequency and severity of extreme weather events.

Replacing existing pipes with new and potentially larger pipes to accommodate future conditions is an expensive, single-purpose solution that yields few co-benefits for communities. Instead, cities will need to rethink their approach to stormwater management and not only reconsider their design criteria (designing for climate projected rainfall rather than recorded, historic data) but also their stormwater management toolbox (supplementing underground piping with above ground multi-purpose, nature-based solutions), often referred to as Blue-Green Infrastructure (BGI)

However, oftentimes BGI is implemented in isolation, ad-hoc, as single-purpose, or disconnected add-ons to existing stormwater management systems, yielding limited flood reduction and little to no natural elements or community co-benefits.

The true potential of multi-functional BGI is found when integrated systematically in the urban fabric as a synergistic connection to urban systems (e.g. existing topography, urban characteristics, stormwater infrastructure, green connections, road systems, parks and public/private spaces) at the neighborhood, municipality, catchment, or city-scale.

This requires a paradigm shift from current stormwater management practices across all agencies, decision-makers, and relevant stakeholders. It requires new modes of co-funding, cost-sharing, and a completely new toolbox of stormwater management typologies and standards.

By demonstrating that BGI has both a social return and an economic return we can create win-win situations for both governments and communities.

A person walking through the flood waters of a street in Princeton as the downpour continues after Hurricane Ida.
Image credit: Simon Kates

What is the citywide potential of nature-based, multi-functional inland flood resilience in New York City?

A new business case for Blue-Green Infrastructure

Cloudburst resilience planning

What is cloudburst resilience planning?

Cloudburst Resilience Planning refers to the paradigm shift in stormwater management that originated in Copenhagen and subsequently applied worldwide.

Cloudburst Resilience Planning introduces an integrated planning methodology to drive a paradigm shift within citywide stormwater management.

The integrated planning methodology combines an inclusive and just planning process with in-depth hydraulic and urban analysis, climate risk assessments, nature-based design toolboxes, and socio-economic business cases to ensure meaningful multi-purpose design.

Stormwater management is no longer solely an environmental engineering task. It is a complex assignment needing both the engineer, the architect, the anthropologist, the biologist, the economist, the community engagement specialist and many other diverse profiles. Only through diverse representation throughout the entire planning and design process can true cloudburst resilience planning succeed.

Together, these diverse disciplines co-design a flexible, multi-function, and nature-based citywide system referred to as a BGI network. This network will not only complement and/or replace grey stormwater infrastructure to cope with future climate conditions, but also bring about more nature, and additional community co-benefits improving everyday life, even when it does not rain.

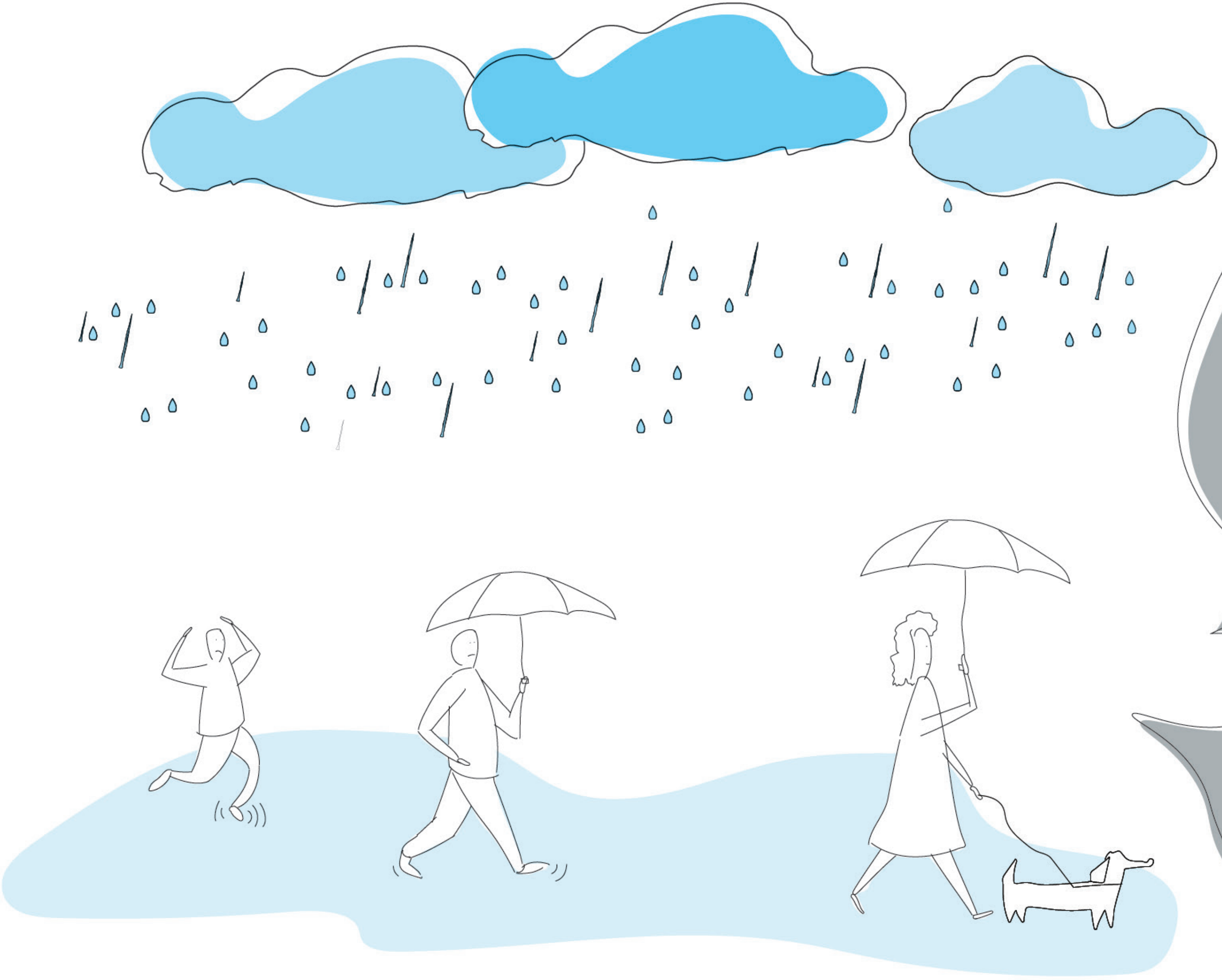
BGI networks offer an opportunity to reintroduce biodiverse and rich nature into our urban space in order to facilitate a human reconnection to nature. The natural features such as added trees, new parks, new smaller natural elements, and larger water features are particularly effective at increasing the societal value of the BGI solutions by e.g. reducing stress and increasing recreation.

The BGI network can be designed to also regulate urban temperatures, clean air and water bodies, offer new recreational spaces, inspire physical activity, and provide new job opportunities.

These co-benefits should be prioritized in dialogue with stakeholders and communities to ensure that the BGI network has the largest societal impact. Ultimately, the co-benefits created will offer a permanent added value to local communities in their everyday life.

We can be sure that BGI's will bring benefits to communities every single day

That is the vision
of cloudburst thinking!



"Cloudburst Management" has developed into an inclusive planning methodology. It pioneers a nature-based approach to stormwater management and flood mitigation that relies on multi-purpose urban designs to maximize community co-benefits.

It provides a solid business case for investing into resilient and nature-positive urban redevelopment.

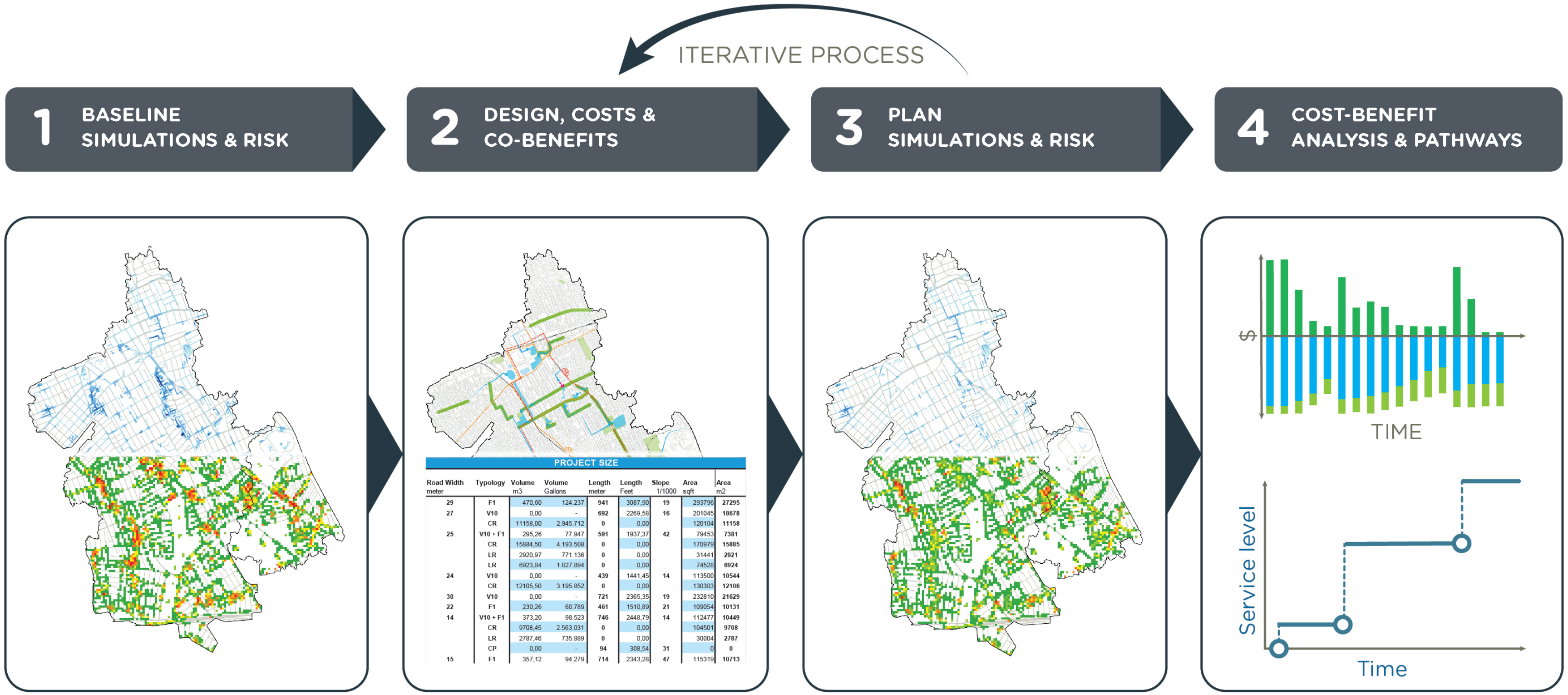
Sketch credit: Ramboll

A young family caught off guard by the sudden and game-changing cloudburst in Copenhagen on July 2nd 2011.
Image credit: Ramboll

> “A “cloudburst” is a sudden, heavy downpour where a lot of rain falls in a short amount of time. Cloudbursts can cause flooding, damage property, disrupt critical infrastructure, and pollute New York’s rivers and Harbor. Cloudburst management implements a combination of methods that absorb, store, and transfer stormwater to minimize flooding from cloudburst events.”

NYC Department of Environmental Protection
Available at: https://www.nyc.gov/site/dep/environment/cloudburst.page

The 4-step approach to cloudburst resilience planning



PROJECT SIZE

Road Width meter	Typology	Volume m3	Volume Gallons	Length meter	Length Feet	Slope 1/1000	Area sqft	Area m2
29	F1	470,60	124.237	941	3087,90	19	293796	27295
27	V10	0,00	-	692	2269,58	16	201045	18678
	CR	11158,00	2.945.712	0	0,00		120104	11158
25	V10 + F1	295,26	77.947	591	1937,37	42	79453	7381
	CR	15884,50	4.193.508	0	0,00		170979	15885
	LR	2920,97	771.136	0	0,00		31441	2921
	LR	6923,84	1.827.894	0	0,00		74528	6924
24	V10	0,00	-	439	1441,45	14	113500	10544
	CR	12105,50	3.195.852	0	0,00		130303	12106
30	V10	0,00	-	721	2365,35	19	232810	21629
22	F1	230,26	60.789	461	1510,89	21	109054	10131
14	V10 + F1	373,20	98.523	746	2448,79	14	112477	10449
	CR	9708,45	2.563.031	0	0,00		104501	9708
	LR	2787,46	735.889	0	0,00		30004	2787
	CP	0,00	-	94	308,54	31	0	0
15	F1	357,12	94.279	714	2343,28	47	115319	10713

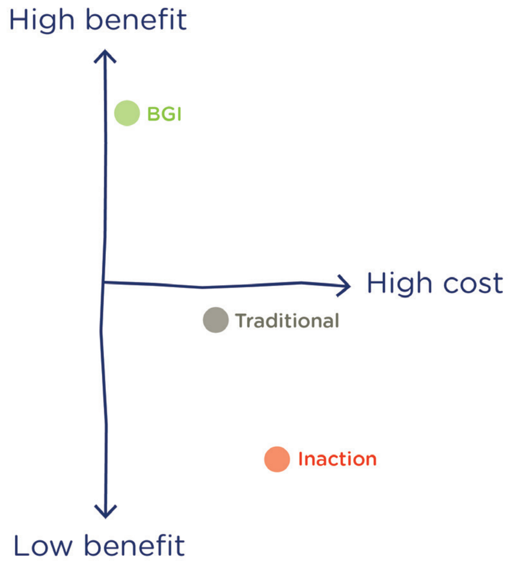
This study utilizes Ramboll's 4-step approach to cloudburst resilience planning, based on experiences from Denmark and around the world. Spatial overlay of datasets and analyses at multiple levels help to identify potential synergies and cumulative effects and provide a solid basis for informed decision-making. The initial flood and risks assessments (1) inform the cloudburst resilience plan development and prioritized co-benefits (2). The effects of the proposed plan are evaluated (3) against predetermined design criteria through further flood and risk modeling.

If simulations show an undesirable outcome, then we go back (2), revising the design until the desirable impacts are reached. Lastly, Cost, benefits, and co-benefits are evaluated (4) in a BCA to secure the overarching argument for the implementation and financing of the cloudburst resilience plan.

Understanding the business case for BGI

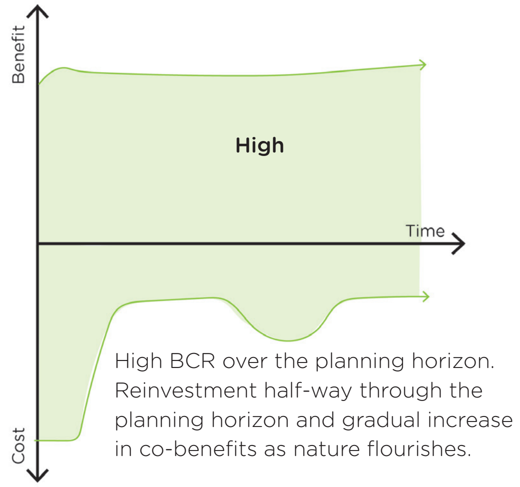
A benefit-cost analysis (BCA) measures the wider positive and negative impacts of a project. Costs and benefits are calculated regardless of who pays for or receives them (i.e., federal government, local government, or residents and property owners) and relates the project to it's wider spatial impact beyond the project boundary to give a socio-economic business case.

The success of the BGI Networks in mitigating flood risk and improving community livelihood is gauged by the Benefit-Cost Ratio (Benefit-Cost Ratio). When benefits outweigh the costs the Benefit-Cost Ratio will be above 1.0.



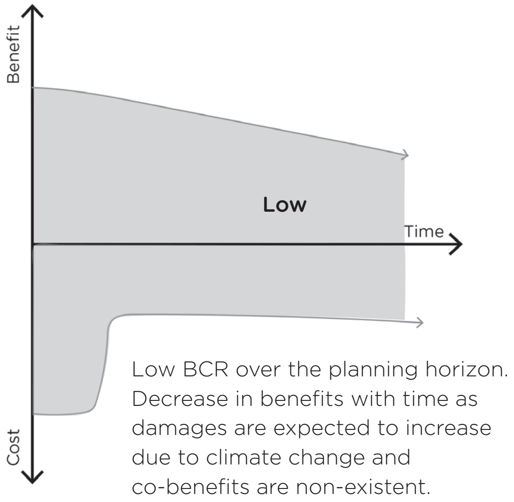
BCA are often oversimplified, only comparing project costs to damage prevention savings. However, carefully designed multifunctional BGI offers unique co-benefits that are not found in gray infrastructure. Ramboll, in collaboration with academia and cities worldwide, has developed a comprehensive approach to quantify these benefits for BCA. These include improved microclimates, reduced pollution, better health, safer traffic, recreation, and carbon storage. Integrating co-benefits enriches the business case, often favoring the project despite its costs.

Cost Benefit Analysis - Blue-Green Infrastructure



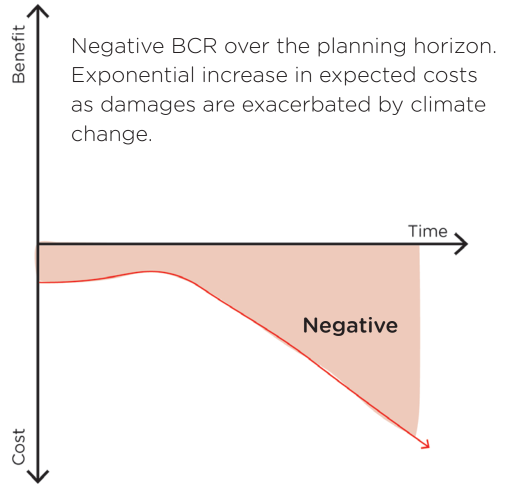
High BCR over the planning horizon. Reinvestment half-way through the planning horizon and gradual increase in co-benefits as nature flourishes.

Cost Benefit Analysis - Traditional Infrastructure



Low BCR over the planning horizon. Decrease in benefits with time as damages are expected to increase due to climate change and co-benefits are non-existent.

Cost Benefit Analysis - Inaction

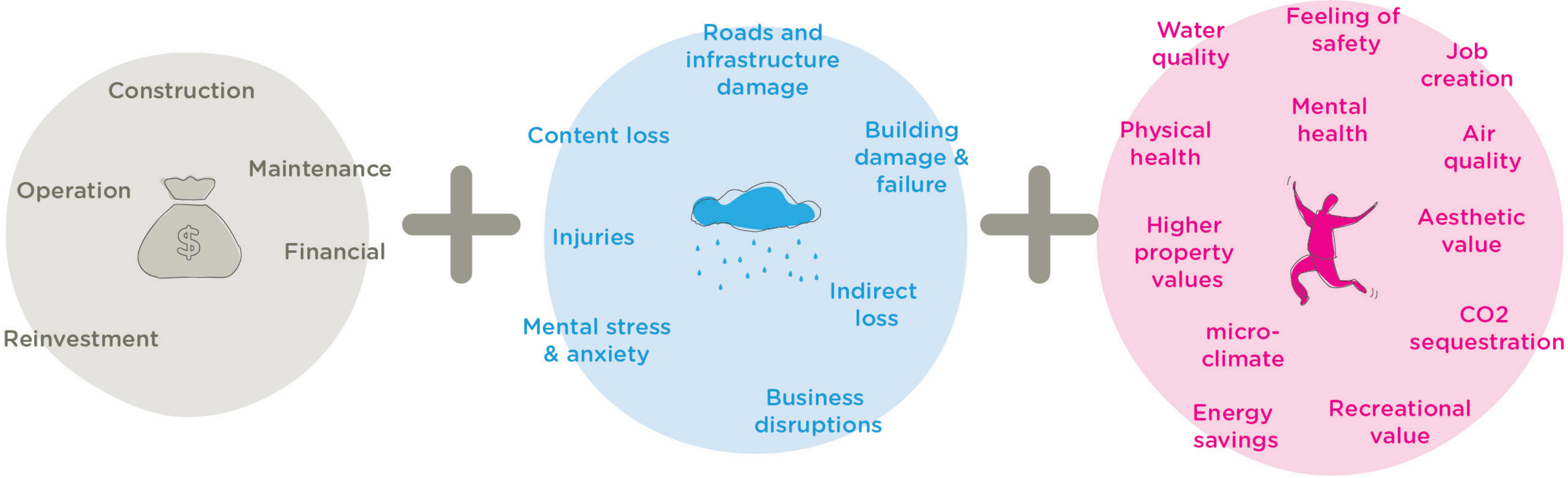


Negative BCR over the planning horizon. Exponential increase in expected costs as damages are exacerbated by climate change.

> “There are risks and costs to action. But they are far less than the long range risks of comfortable inaction.”
>
> John F. Kennedy

Remiseparken in Copenhagen
Image credit: Ramboll
Ramboll revitalized Remiseparken in Amager, a once dilapidated and neglected urban area located south of Copenhagen. The area has been transformed into a lively urban park adorned with newly planted trees, bushes, and vibrant flowers. The park has also implemented effective cloudburst management solutions, such as a basin and a long gutter, ensuring efficient stormwater management.

Monetizing the effects of the business case



COST
INVESTMENTS

Investment costs include overall financing expenses, constructions costs (incl. design supervision, site accommodation, winter measures, contingencies etc.), and maintenance & operational costs (incl. reinvestment of components with shorter lifetime than the overall costing period).

BENEFITS
REDUCED RISK

Benefits include avoided costs/losses from flooding such as physical damages to properties, loss of service/function (e.g., temporary or permanent business closures, temporary disruptions to transportation services, water, and electricity), displacements costs, or emergency management costs.

CO-BENEFITS
ADDED VALUE

Co-benefits refer to the long-term added values derived from the natural elements introduced through the BGI Networks including improved air quality, water quality, improved physical health and recreation, improved micro-climate, and carbon storage. Some co-benefits are measured as saved expenses to society, other as created values.

Methodology for a citywide resilience business case

How to develop a citywide business case for New York City?

①

City-wide flood risk screening

Citywide flood risk screening to identify representative case areas

Flowlines and flooded areas are identified by a city-wide model, overlayed with land-use information and damage costs to estimate the spatial flood risk across the city and the total cost of "do-nothing" scenario.

The citywide risk assessment informs the selection of representative case areas validated against vulnerability parameters.

②

Representative BGI networks

Case area BGI Networks and business cases

Case area delineations are refined against topography, land-use, etc.

A network of connected BGI typologies is developed to mitigate flooding from the future 10-year and 50-year storm respectively.

The BGI Networks are quantified in investment costs, reduced risk, and co-benefits collated in a BCA.

③

City-wide business case

Upscaling from case areas to citywide business case

Case area business cases for both the 10- and the 50-year design storm are upscaled to a citywide BCA using a linear correlations.

A spatially distributed BCA is developed citywide along with a concluding BCA for the city as a whole.

Data used for flood model

The flood model built for this project is a static, citywide, spatial model simulating overland flows, accumulation, and flooding. Rain data from existing and future climate predictions are used in the study.

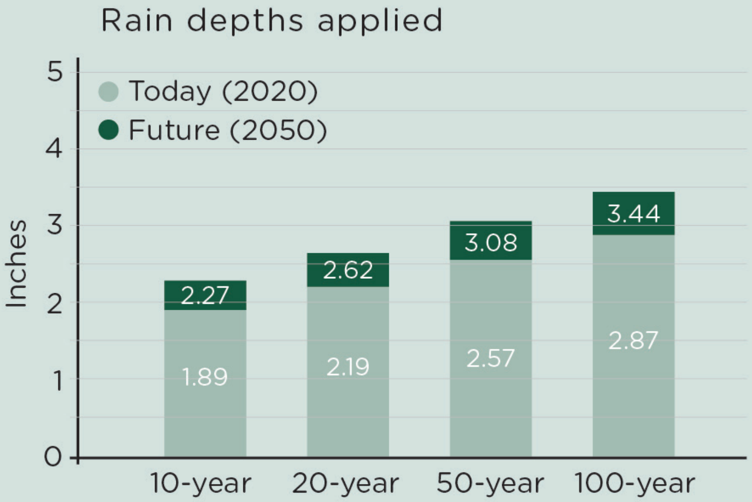
Firstly, Intensity-Duration-Frequency (IDF) curves are prepared using historical precipitation data from National Oceanic and Atmospheric Administration (NOAA). The 30-5801 station is used to represent the IDF for all 5 NYC boroughs. The station is located in Central Park. Only return periods of 10, 50 and 100 years are applied in this project.

To account for future climate change impact on precipitation patterns a Climate Factor (CF) is applied to the rainfall data. The CF is developed using climate projections from Cornell University (Northeast Regional Climate Center, 2015). These projections are based on a downscaling of a global climate model output for the four Representative Concentration Pathway (RCP) scenarios by Intergovernmental Panel on Climate Change (IPCC). Projections are available for three future projection periods: 2010-2039, 2040-2069, 2070-2099. The high emission RCP 8.5 scenario in 2040-2069 (referred to as “2050”) from Cornell University is chosen as a conservative climate scenario for a medium future (2050) planning horizon.

The same methodology has previously been applied in cloudburst projects with NYC Department of Environmental Protection (DEP) e.g. in the Cloudburst Pilot master-plan for South-east Queens. CF will vary slightly with rain duration and return period, however an average of 1.2 is applied for all durations and return periods given the high level of analysis conducted.

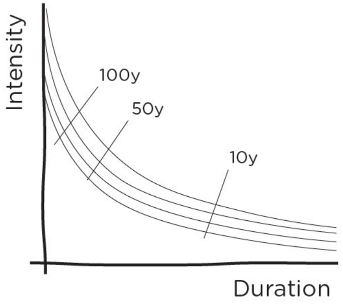
Secondly, a box rain is used to calculate the overall amount of stormwater within a catchment and the spatial flood exposure. Based on an analysis of estimated catchment sizes and corresponding time of concentration a duration of 60 minutes is chosen for each return period applied.

The capacity of the existing drainage system is estimated to a 5-year storm in current climate based on the NYC DEP Drainage Plan.



Summary of input data for flood modeling

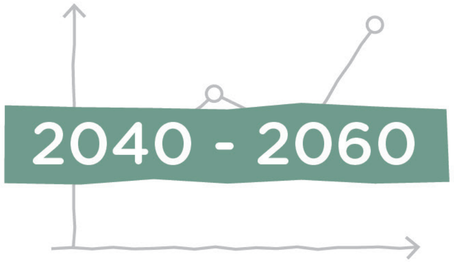
Rain station 30-5801



IDF curves from NOAA

1.2

Average climate factor based on data from Cornell University



IPCC RCP 8.5 scenario for years 2040-2060 (“2050”)

Rain intensity duration for box rain

Estimated capacity in existing drainage system

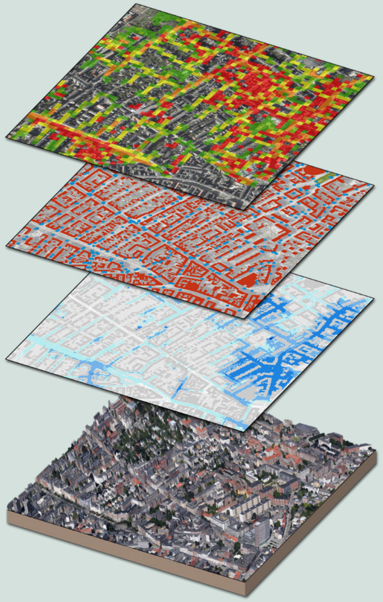
Quantifying flood risk

A climate risk analysis assesses the consequences over time of a given climate hazard. It can be expressed as the Expected, Annual Damages (EAD) in $/yr and provide a spatial overview of the distribution of risk.

Risk is the product of hazard probability and area vulnerability. Probability relates to the climate hazard and indicates how often the event, in this case flooding, occurs. Vulnerability relates to the given area and is a product of the exposure, sensitivity, and adaptive capacity of the systems, assets, and/or communities in the area.

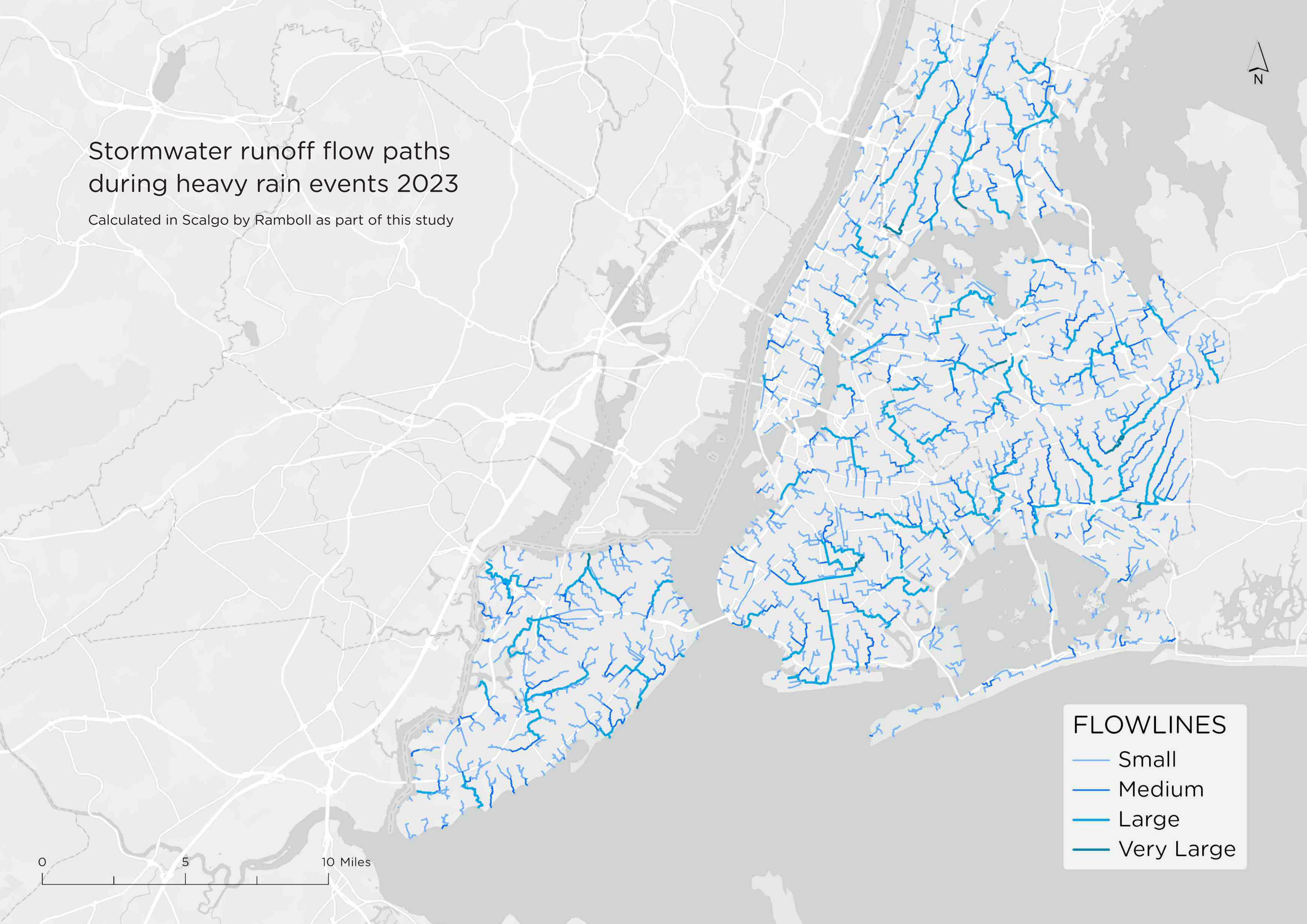
For example, an older construction will often be more sensitive than a brand-new building in the same location, but if measures (adaptive capacity) are in place to ensure the older construction isn't exposed in a flood event, the total vulnerability (and eventually risk) will be much lower than without flood measures.
To assess the risk (or Expected Annual Damages) over time from extreme rain, flood simulations of several rainfall sizes ("return periods") are required. This is to account for the fact that in any given year, there is a likelihood of any and all rain event(s). In this climate risk analysis a 10-yr rain event is simulated, as well as a 50-yr and a 100-yr rain event. Furthermore, simulations are run in both a present day climate and a predicted, mid-century climate (RCP8.5). The flood model results are subsequently loaded into Hazus to estimate the potential consequences of the rain events. Hazus is a nationally standardized risk modeling tool managed by FEMA, that identifies areas with high risk for natural hazards and estimates economic impacts. Hazus calculates damages and losses using functions that relate the inundation depth to the degree of damage for various categories such as buildings, utilities, and transportation. Additional costs such as social impacts, potential diseases, etc. have been accounted for with a factor scaling from emerging climate risk literature.

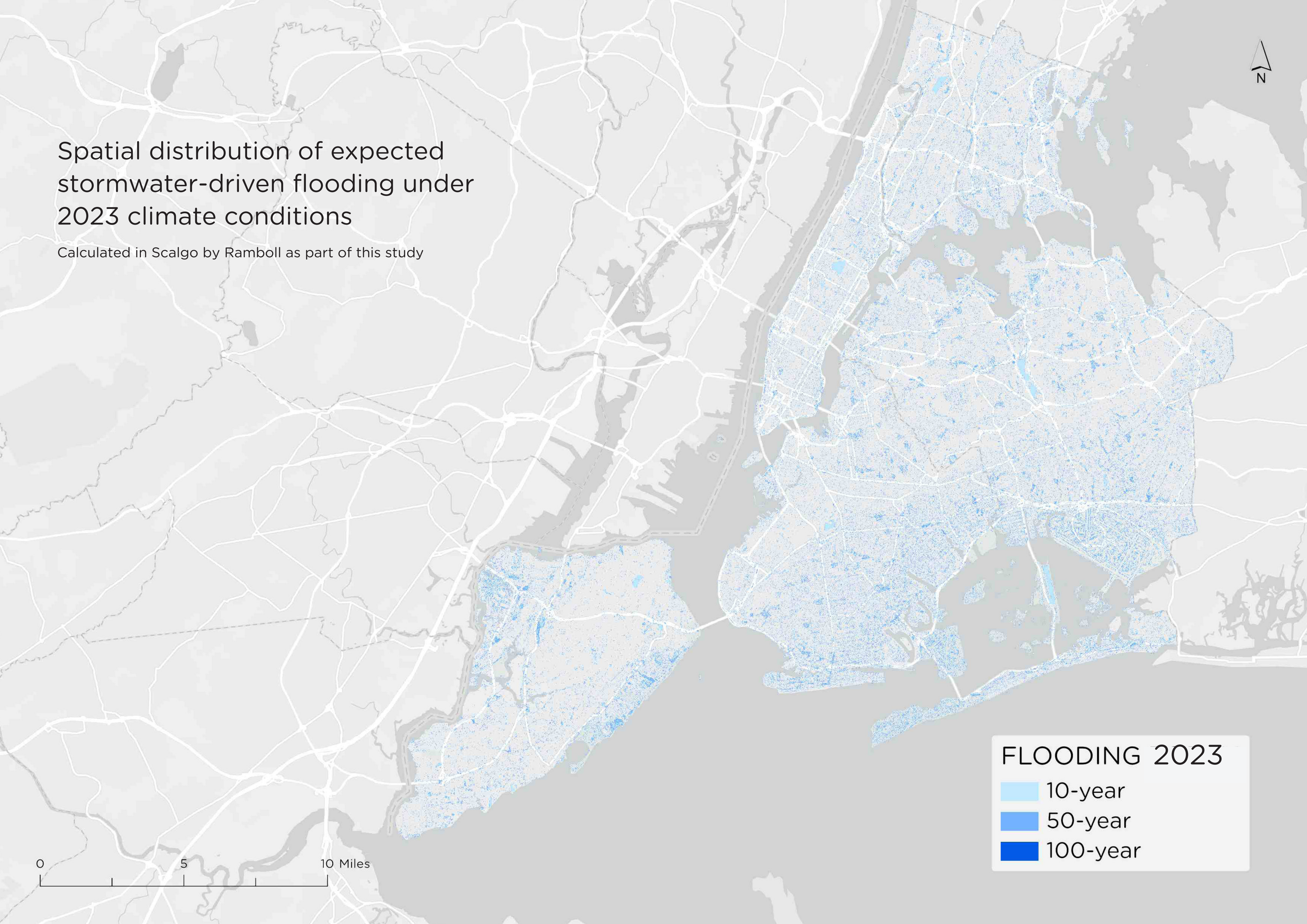
Risk can be expressed as the expected, annual damages in $/yr, and is a result of integrating the damages and losses from flooding over all probable rain events in a year.



Stormwater runoff flow paths during heavy rain events 2023

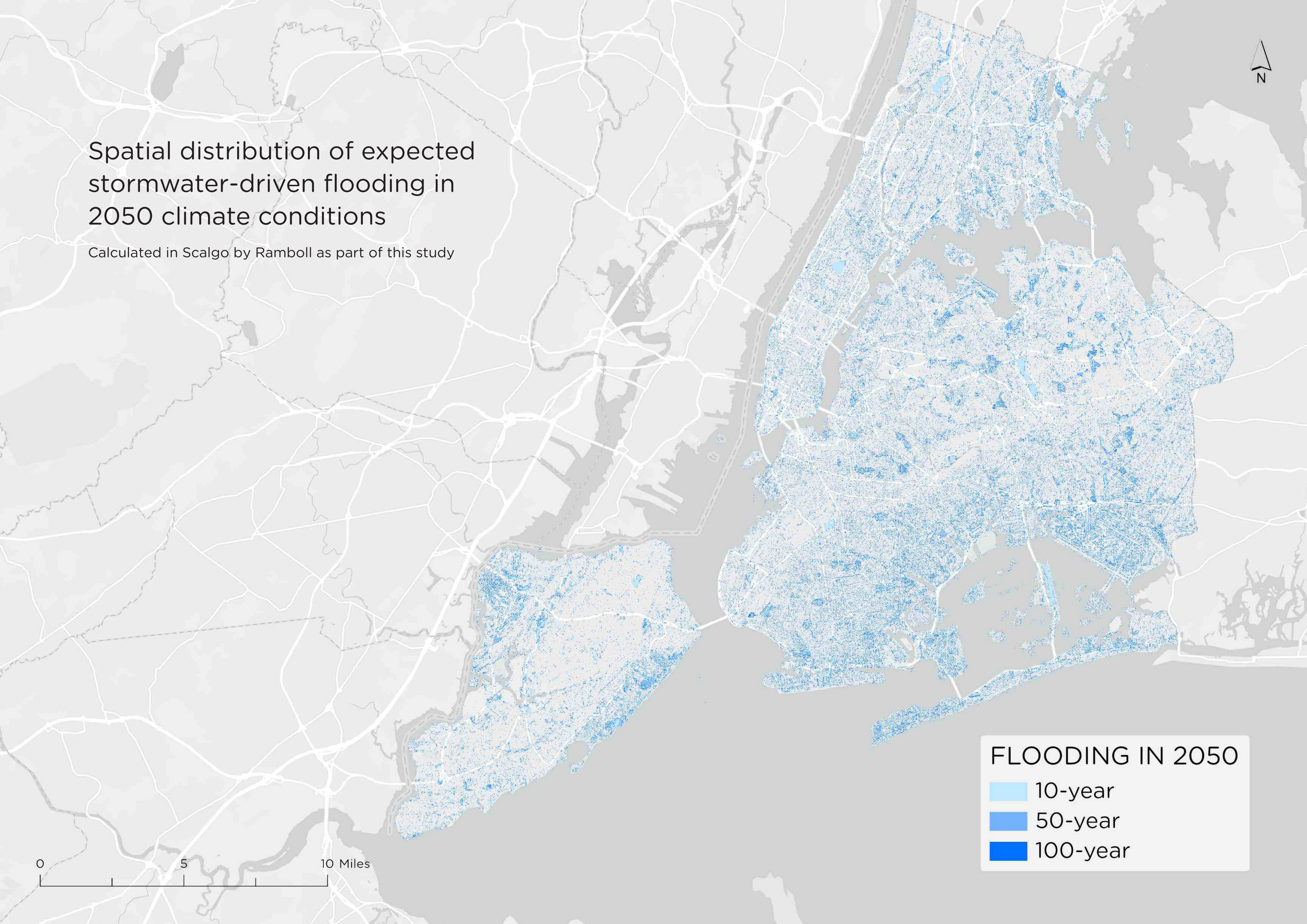
Calculated in Scalgo by Ramboll as part of this study





Spatial distribution of expected stormwater-driven flooding under 2023 climate conditions

Calculated in Scalgo by Ramboll as part of this study

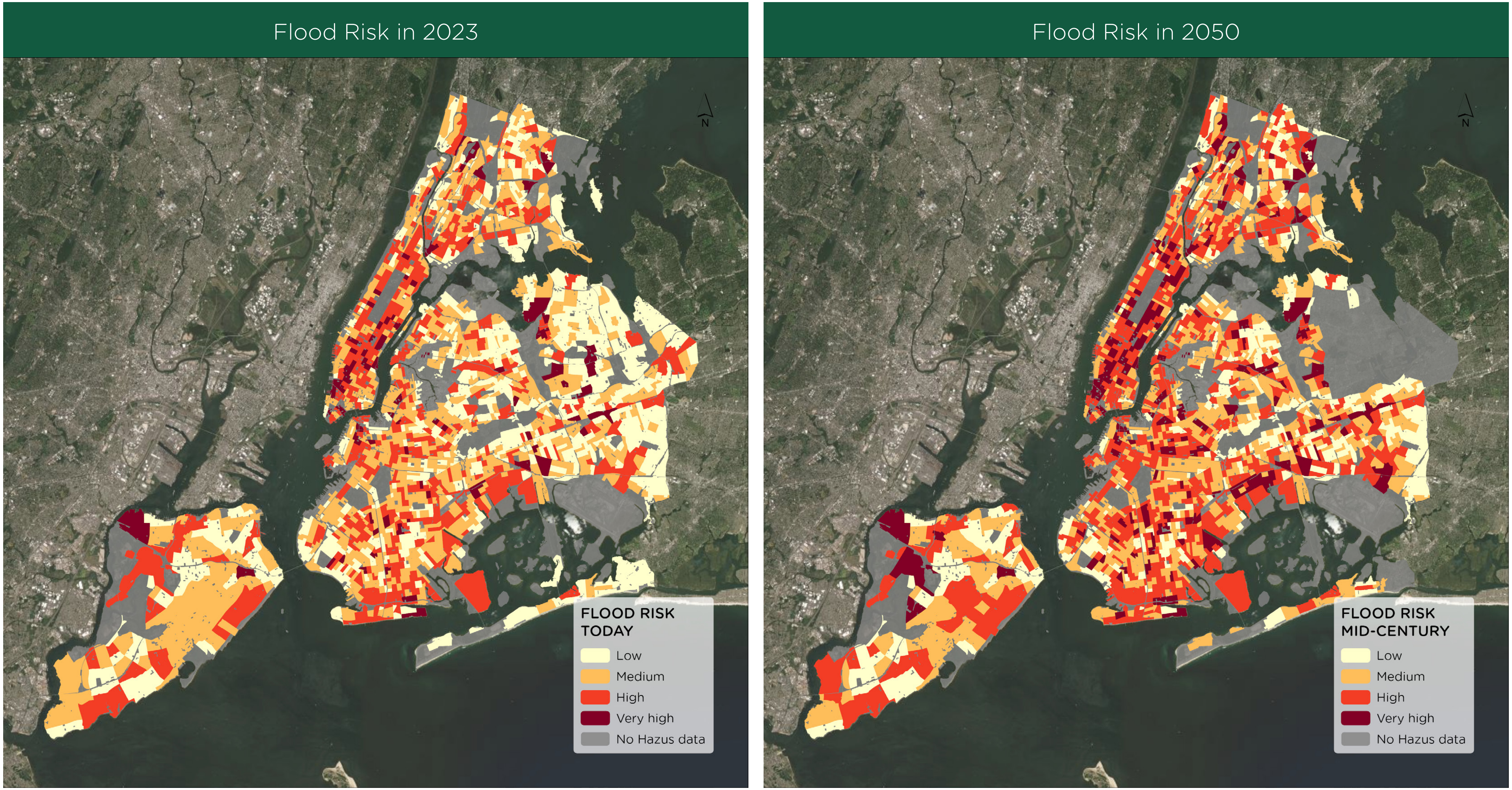


Spatial distribution of expected stormwater-driven flooding in 2050 climate conditions

Calculated in Scalgo by Ramboll as part of this study

Spatial distribution of monetized flood risk

Based on Hazus data from FEMA overlayed with the Scalgo calculations from Ramboll prepared as part of this study.



Flood Risk in 2023

Flood Risk in 2050

Identifying representative case areas

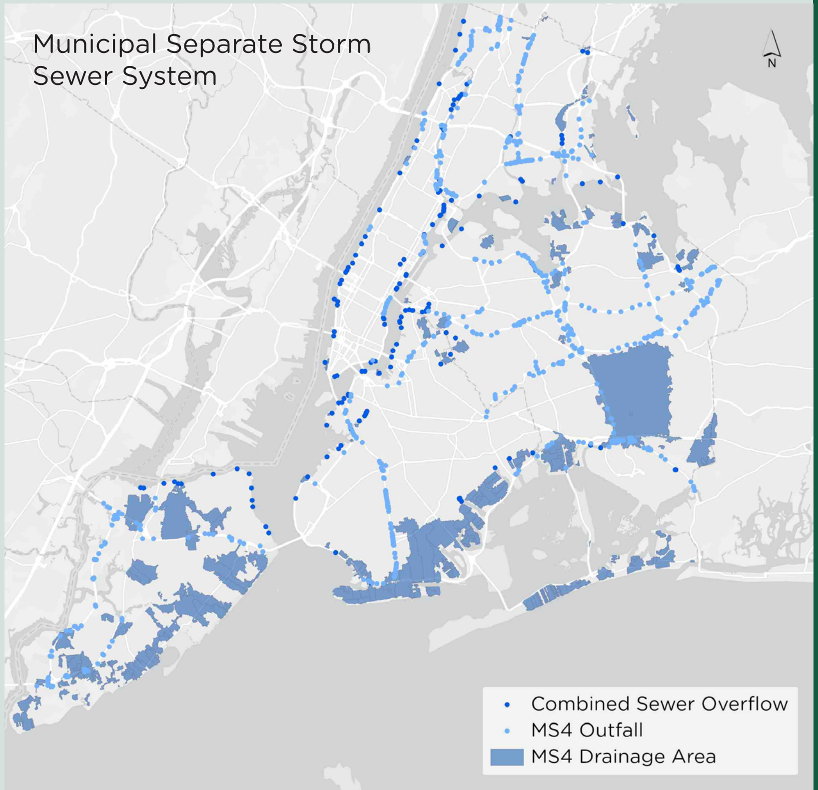
The case areas selected for this study are based on spatial analysis of (A) hydraulic and hydrological parameters, (B) physical and spatial conditions, and (C) social and health-related characteristics across New York City. The case areas represent the diversity of the city and acknowledge that the business case for BGI may perform better in some neighborhoods of NYC than in others. The selected areas are not officially proposed plans nor recommendations for prioritized areas.

The proportion of flooding within each case area aligns with the overall proportion observed across the entirety of NYC. This means that the flooded areas/ volumes per square miles in the case areas are similar to the flooded area per square mile citywide.

The case areas are refined according to topography, land-use, etc. to enhance the hydraulic analysis.

The Manhattan case area serves as a validation case, where the costs applied in the business case match the actual costs. It was developed by Ramboll in 2018 and is used to quantitatively validate the CAPEX and OPEX estimated in this study.

When upgrading separate or combined sewer catchment areas, integrating BGI significantly reduces initial infrastructure upgrade needs, and offers substantial co-benefit savings. In addition, BGI provides decentralized stormwater treatment savings in separate systems and reduces operation and infrastructure upgrade expenses.



A - Hydraulic and hydrological parameters

All case areas represent approximately the same level of flooding and runoff coefficient/density

- Runoff coefficient
- Scale of flooding

B - Physical and spatial conditions

All case areas cover a variety of land use parameters:

- Street widths
- Air quality
- Area of parks
- Land Use
- Urban Heat Index
- Proximity to water fronts

C Social and health-related characteristics

The case areas cover a variation of socio-economic parameters to be representative of NYC

- Social Vulnerability (See SVI map on p78)
- Environmental Justice Area

Developing master plans for each case area

Case areas are selected and refined

Analyze flooding
Detailed analysis of the flood extent and early phase diagnostics of flood cause. Determine which flooded areas are significant/unacceptable and should be alleviated.

Sub-divide into catchments
Based on topography, flowlines and potential measures the case areas are subdivided into smaller catchments to be able to detail the needed conveyance, retention and treatment capacity.

Masterplan developed for the future 10-year

Locate central detention
Identifying suitable larger areas to temporarily store stormwater.

Connect to detention
Establishing gravity-based conveyance from flooding to the identified detention sites or outlets.

Detain upstream
As a supplement to the more cost-efficient central detention, smaller scale upstream detention is needed. 10% of accumulated stormwater volume in each catchment is assumed managed in Green Stormwater Streets.

Divert outside area
Diverting stormwater to parks or other suitable areas outside the case area can be necessary in situations where no parks are available within the case areas.

Cleanse and release
Near waterfronts and where parks are unable to receive water, rainwater is conveyed to a cleansing biotope (or traditional stormwater filtration with buffer volume and by-pass) before released to a recipient.

Masterplan developed for the future 50-year

Up-size to 50-year storm
The capacity of the BGI-network plan is upgraded to a 50-year design storm in 2050 using the same identified areas for storage and streets for conveyance. Both storage and conveyance have been upscaled to accommodate volume and flow from a future 50-year event.

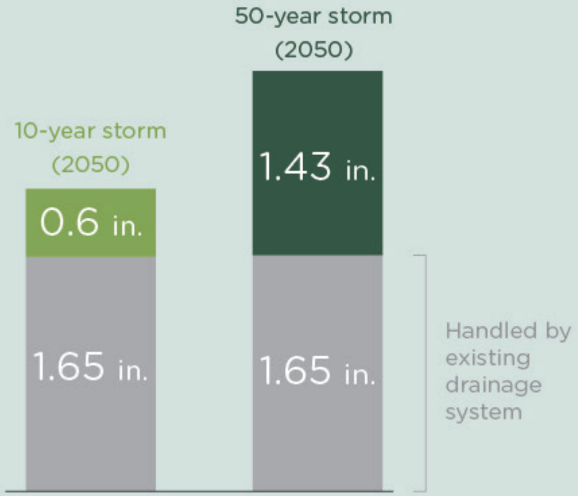
Additionally, the number of detention streets has been increased to detain a larger portion (15% of the total in detention streets) of the flood-water upstream in smaller scale BGI measures, such as Green Stormwater Streets.

Data and assumptions applied in the BGI Networks

Developing water balances

BGI Networks are designed for a 10-year design storm in 2050 (2.25 inches) and a 50-year design storm in 2050 (3.08 inches) using 1-hour intensities. A current 5-year event (1.65 inches) is used as the capacity of the existing drainage system.

Hence, the excess water amounts to 0.61 inches for the 10-year design storm and 1.43 inches for the 50-year design storm.



Prioritizing co-benefits

Many of the co-benefits derived from using BGI for stormwater management are tied to the increase in recreational space, vegetation and trees. Hence, the typologies applied prioritize additional greening where possible. Existing vegetation and trees are accounted for to derive at a realistic estimate of proposed new vegetation. The streets are categorized according to their width and potential additional trees per foot and potential additional vegetation per sq ft is estimated accordingly.

Green Stormwater Street

Stormwater Conveyance Road

Estimating costs

The construction cost estimates used in this study are based on similar projects in the US averaged into unit prices which include a percentage for construction management, engineering design services, and contingencies. Annual maintenance costs are estimated to 2.5% of construction budget. A full reinvestment of the plan is accounted for 40 years after the initial construction start date to take the expected life-time of BGI into account. The unit prices for the Right of Way (ROW) Typologies average with the width and capacity of the street. The unit price for the parks and public housing BGI Typologies include recreational amenities in addition to the blue and green features.

BGI maintenance as 2,5% of construction budget

40

Full reinvestment assumed every 40 years

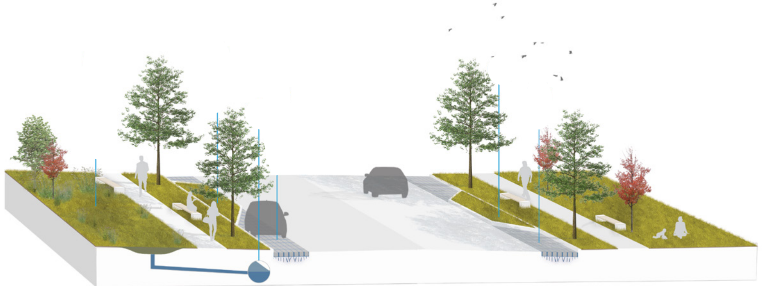
Right of Way BGI typologies applied in the study

By expanding NYC DEP's toolbox of BGI, we can maximize benefits and economic return. Floodable streets are designed to detain smaller amounts of stormwater and to move water through the catchment area so that it can be stored in a controlled way.

Each floodable street typology includes a combination of hydraulic elements that hold water and convey it downstream. These hydraulic elements include bioswales, rain gardens, underground storage cells, and new stormwater pipes to move water underground where surface measures are not appropriate.

The potential co-benefits of each Right-of-Way Typology include increased traffic safety, improved air quality, and energy savings.

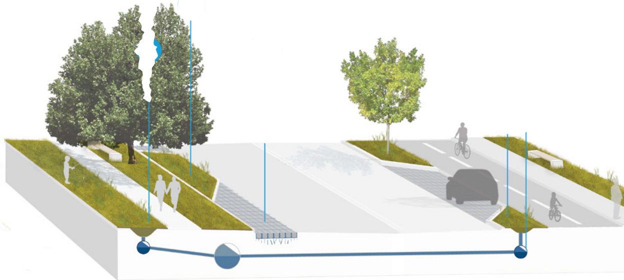
BGI streets are designed to be safe up to 4" of in a 100 year storm.

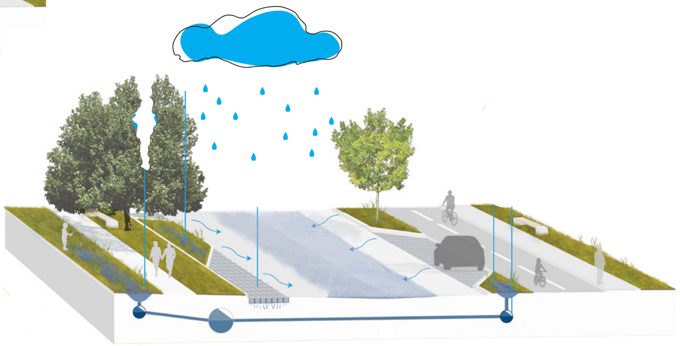


Green Stormwater Street

Local detention and controlled release of stormwater runoff to sewer system.

Width:	30-60 ft
Cost:	3,000 - 11,000 USD/ft
Storage capacity:	150 - 450 gallon/ft





Stormwater Conveyance Road

Conveying stormwater from flooded areas to Central Detention Areas.

Cost:	500 - 1,500 USD/ft
Flow capacity:	90 - 600 gallon/s

Open Space BGI typologies applied in the study

Floodable open spaces present a great opportunity to detain large stormwater volumes within urban areas. They can be located throughout the catchment areas and can be designed at various scales, depending how much space is available, compatible uses, community preferences, and the volume of water that needs to be detained.

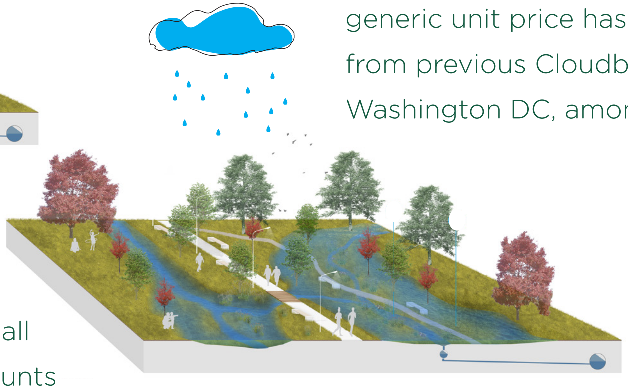
Open space BGI typologies are designed to manage daily rain without any impact on the recreational functions of the space. During extreme rain events controlled inundation of select areas will then be temporarily activated.

The potential co-benefits of Open Space typologies include improved recreation, physical activity, carbon storage, and air quality.

Floodable Parks

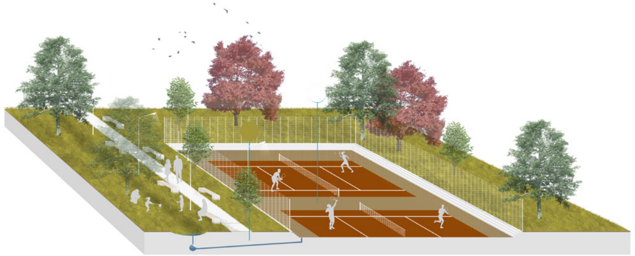
Sizes and capacity vary according to storage needs, topography, and space availability. A generic unit price has been used, developed from previous Cloudburst projects in NYC and Washington DC, amongst others.

Cost: 10-15 USD/gallon



Floodable Athletic Fields

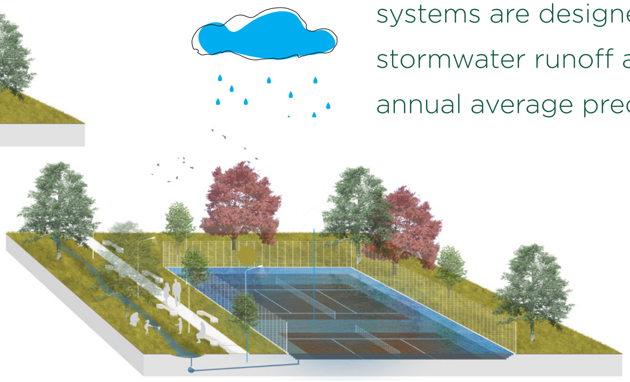
Football and soccer fields, tennis and basketball courts, etc. are excavated to detain large amounts of stormwater during extreme rain events.



Cleansing Biotope

Cleansing biotopes and stormwater filtration systems are designed to manage excess stormwater runoff and filtrate 95 % of the annual average precipitation.

Cost: 750,000 USD



Designing for community co-benefits

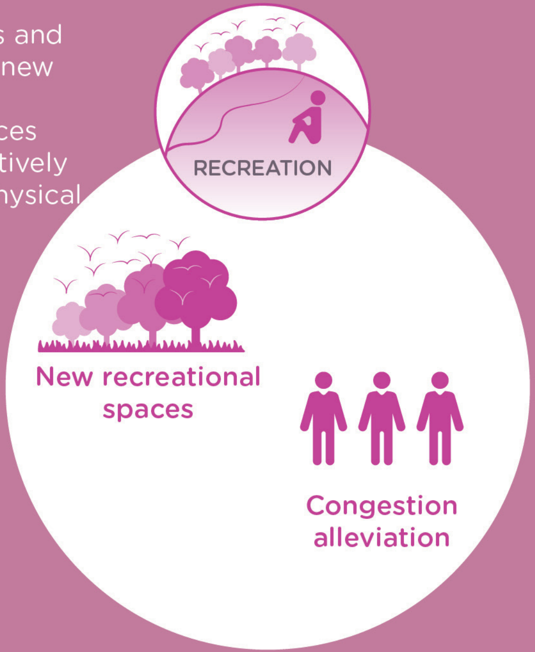
By designing with nature-based solutions, urban liveability is greatly increased through the reintroduction of rich and biodiverse recreational spaces, where both people and nature flourish. By integrating these living systems as part of the BGI toolbox, cities build a new business case for climate resilience and quality of life that go beyond the pure benefits of flood mitigation. This new business case also help capture the added value to society, refered to as co-benefits. Working with nature and community co-benefits in our toolbox enables a new approach that favors multi-purpose design, reintroduces nature, and prioritizes community needs to ultimately deliver a more equitable process as well as design.

BGI can be designed to improve air and water quality, reduce noise, improve mental and physical well-being, reduce the urban heat island effect and the loads to the wastewater treatment plant, improve the quality of the aquatic environment by treating stormwater runoff, increase carbon storage through planting of new trees, and many more aspects.

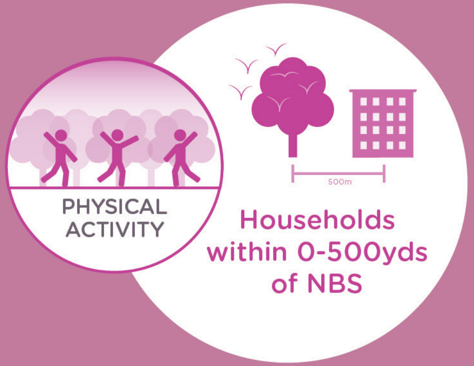
As result of proposed BGI interventions for each case area, the following co-benefits are monetized with Ramboll's NBS Value tool: (1) increased recreational space, (2) improved air quality, (3) opportunities for physical activity, (4) increased carbon storage, (5) energy savings through micro-climate regulation, and (6) increased traffic safety.

The NBS Value tool contains a large database with best-practice studies and valuation methodologies for added values. It combines socio-economic information, e.g. population density, with spatial data, e.g. location of newly proposed recreational space and the number of households within its proximity.

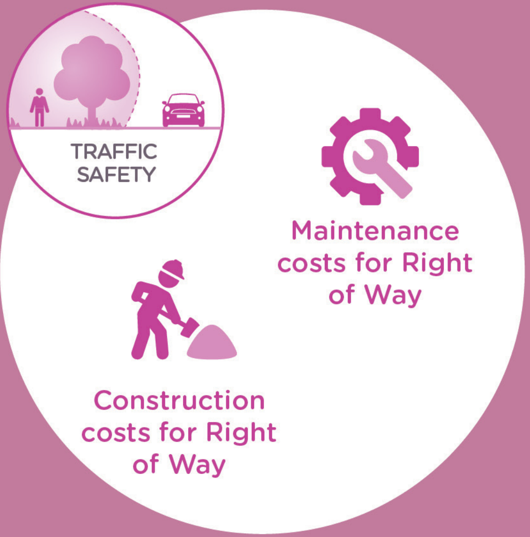
Increased access and reconnection to new or improved recreational spaces contributes positively to mental and physical health.



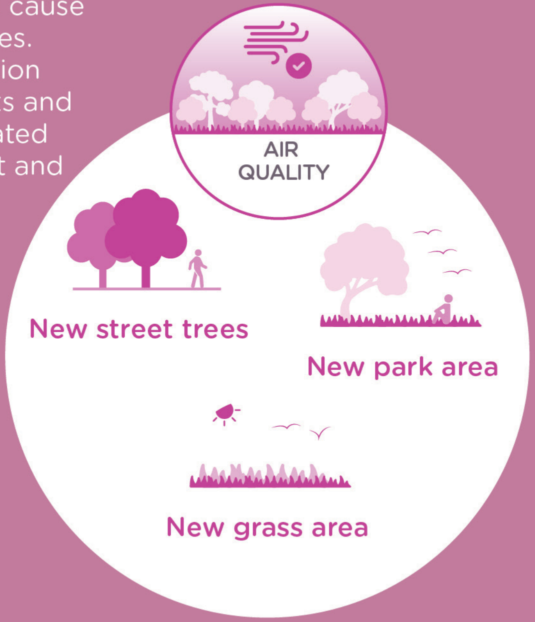
Improved outdoor space for recreation increases physical activities which contribute to the general health of the community and reduces the societal costs associated with an inactive lifestyle.

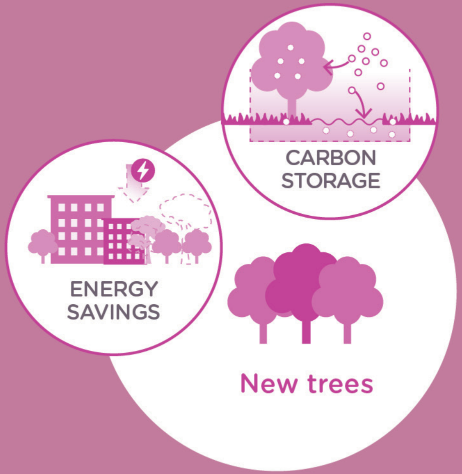


BGI designed with traffic calming elements in public streets or providing new/improved bicycle and pedestrian facilities can increase traffic safety.



Air pollutants affect human health and cause respiratory diseases. Increased vegetation removes pollutants and help avoid associated medical treatment and lost productivity.





Trees can reduce CO2 level in the air by binding it in the organic material through photosynthesis, called carbon sequestration.

Trees can also provide shade to reduce heat energy absorbed by hard surfaces and increase transpiration that cools the air.

Key parameters and conditions in the benefit-cost analysis

The Benefit-Cost Analysis (BCA) in this study follows The Federal Emergency Management Bureau (FEMA) guidelines.[1]

The standard discount rate of federal programs in the US is 7%[2]. Some communities have raised concerns with meeting the BCA requirement to access funding through FEMA's programs, which traditionally request a benefit-cost ratio of 1.0 or greater.

These concerns are the reason why in 2022, FEMA introduced a quite ambitious alternative cost-effectiveness methodology: "A mitigation project may be considered cost-effective if, when using the 7% discount rate, the Benefit-Cost Ratio is at least 0.75 or greater, and if at the 3% discount rate the Benefit-Cost Ratio is at least 1.0 or greater, and the mitigation activity benefits disadvantaged communities, addresses climate change impacts, has hard to quantify benefits, and/or is subject to higher costs due to the use of low carbon building materials or compliance with the Federal Flood Risk Management Standard."[3]

This study applies 7% discount rate but shows results with a 3% discount rate as a sensitivity consideration.

Time Horizon	2023-2123 (100years)
Hazus Version	Hazus 6.0 (released November 2022)
Discount Rate	Default 7 %. Results for 3 % are also shown in accordance with FEMA's Building Resilient Infrastructure and Communities grant program.
Design Level	10-year storm in 2050 and 50-year storm in 2050, RCP 8.5
Construction Period	2023-2038 (15 years)
Re-investments	2073-2083 (occurs 50 years into planning horizon and takes 10 years)
Maintenance	2.5% of construction costs starting at end of construction period
Damage Reduction Starts	10 years into construction period (2033)
Positive Business Case	Benefit-Cost Ratio above 1.00

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[1] URS Group, Inc., "BCA Reference Guide," Federal Emergency Management Agency Department of Homeland Security, Washington, DC, 2009.

[2] Office of Management and Budget (OMB), "Circular A-94: Guidelines and discount rates for benefit-cost analysis of federal programs," 15 March 2022. [Online]. Available: https://obamawhitehouse.archives.gov/sites/default/files/omb/assets/a94/a094.pdf. [Accessed 15 January 2023].

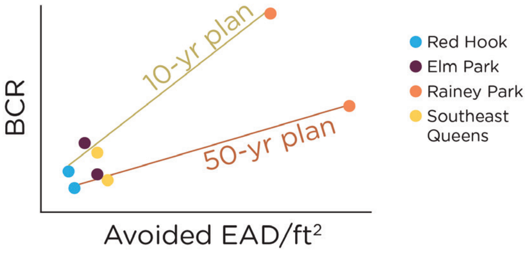
[3] Federal Insurance and Mitigation Administration, "Alternative Cost-Effectiveness Methodology for FY2022 BRIC and FMA," 6 October 2022. [Online]. Available: https://www.fema.gov/sites/default/files/documents/fema_alternative-cost-effectiveness-methodology-for-FY2022-BRIC-and-FMA.pdf. [Accessed 15 January 2023].

Upscaling to a city-wide business case

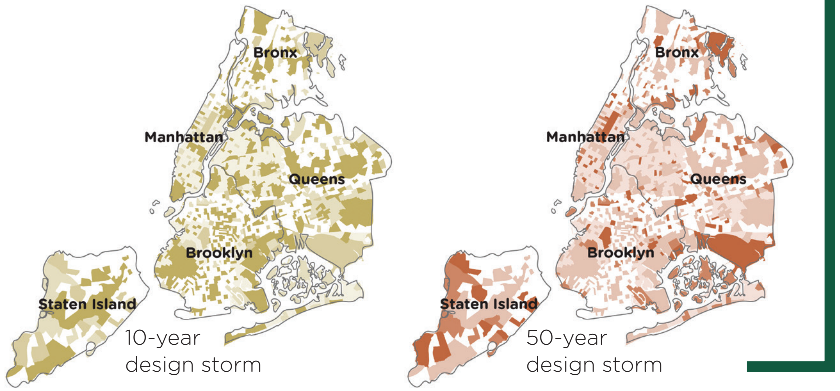
To upscale results to a citywide resilience business case, a correlation between the present value of the avoided Expected Annual Damages (EAD) per area unit and the Benefit-Cost Ratio (BCR) is estimated for each case area. Correlated linear trends (A) between present value of EAD/sqft and BCR are estimated for both the 10-year and the 50-year design storms.

The present value of avoided Expected Annual Damages are calculated for all census tracts modeled (B). The darker the color, the higher the avoided Expected Annual Damages. Lastly, the Benefit-Cost Ratio for all census tracts is calculated (C) based on the avoided Expected Annual Damages in each tract and the trends from the case areas.

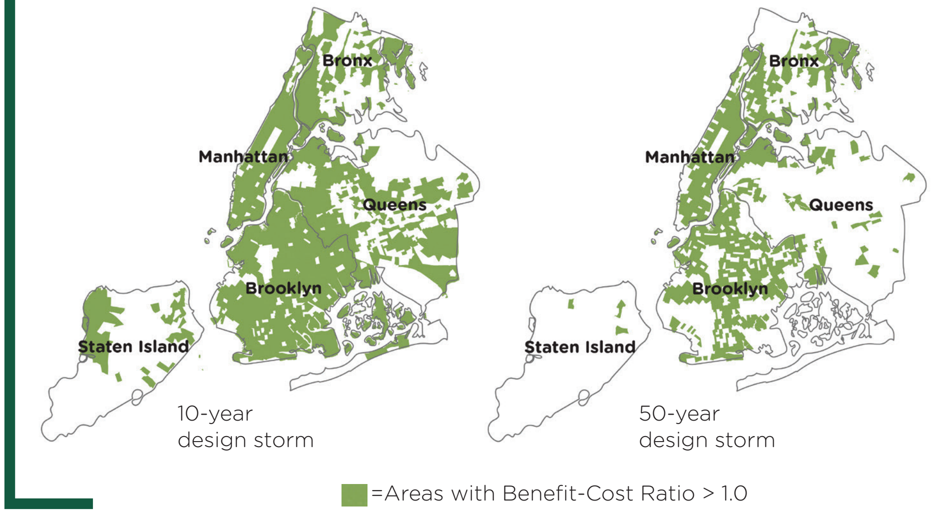
A Define linear trends: y= m × x + b



B Calculate avoided EAD/ft² for all census tracts in both plans



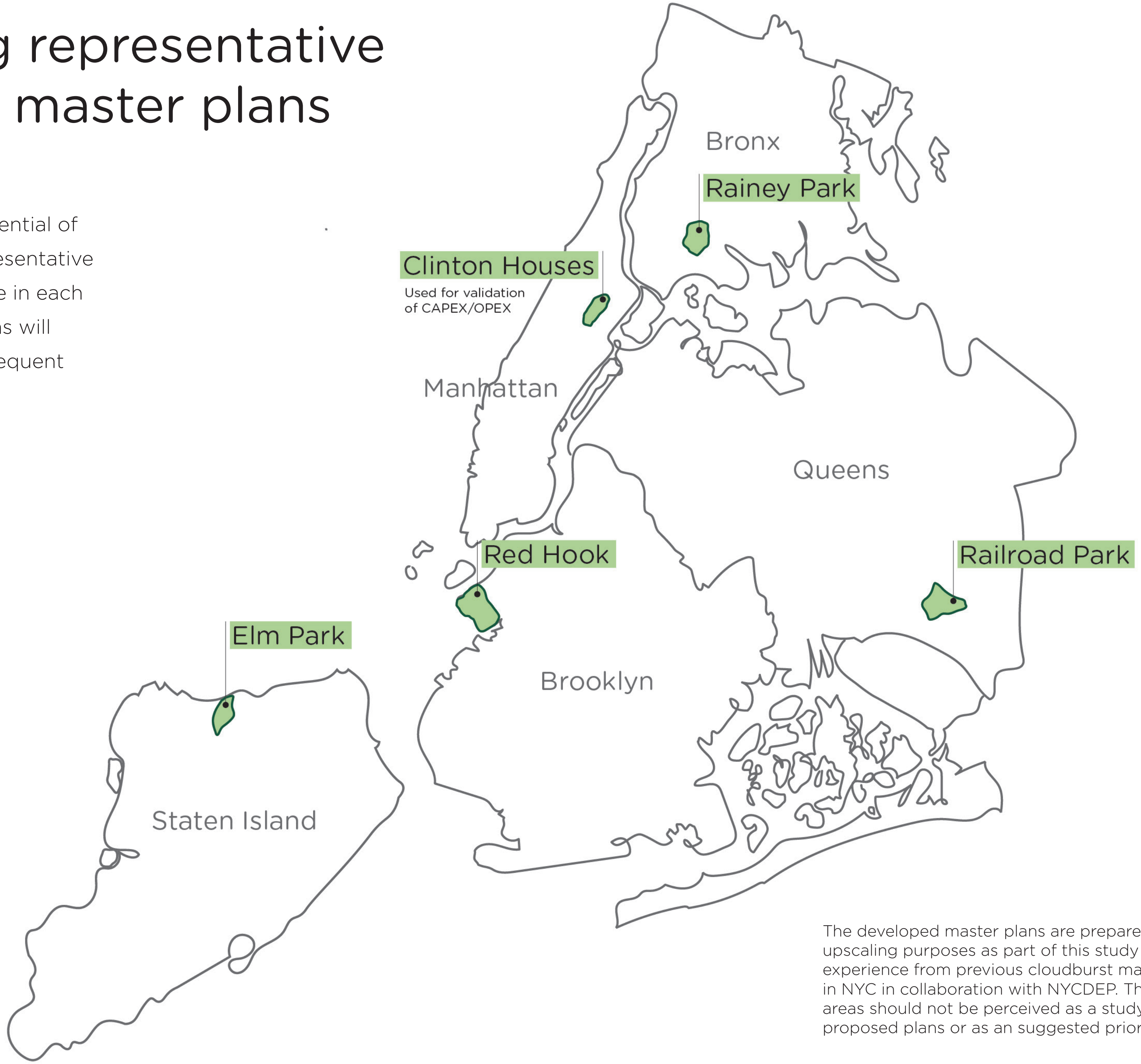
C Calculate BCR from linear trends: m × [Avoided EAD/ft²] + b = BCR



5 case area BGI Networks for upscaling

Developing representative cloudburst master plans

To assess the city-wide potential of multi-functional BGI 5 representative case areas are selected, one in each Borough. These 5 case areas will make up the basis for subsequent city-wide upscaling.



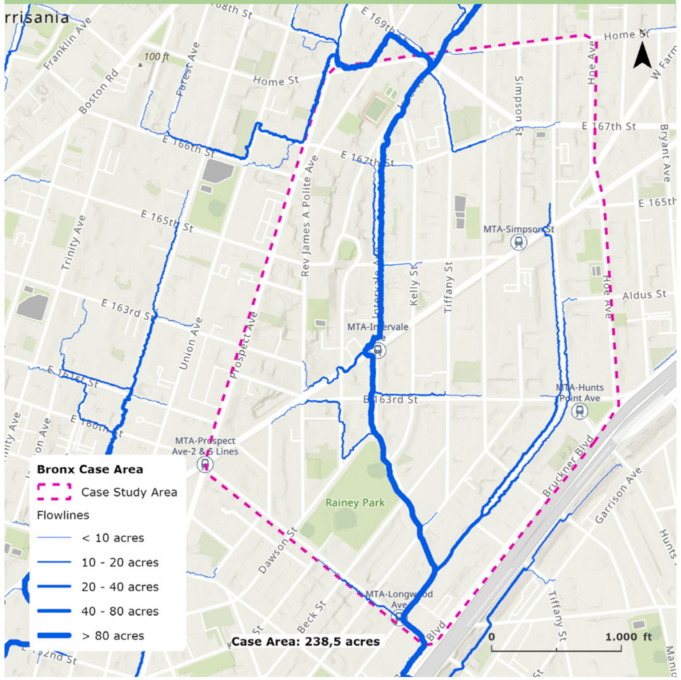
The developed master plans are prepared for upscaling purposes as part of this study based on experience from previous cloudburst master plans in NYC in collaboration with NYCDEP. The case areas should not be perceived as a study of actual proposed plans or as an suggested prioritization.

Getting to know the case area: Rainey Park, The Bronx

Home to nearly 30,000 residents, this case area in Longwood in The South Bronx encompasses mostly high density multi-family homes, three schools (Pharos Academy Charter School, X248 The Metropolitan High School, X530 Longwood Preparatory Academy), a park (Rainey Park), and a religious institution (St. Athanasius Roman Catholic Church). The buildings in the neighborhood are largely two to six-story residential buildings, with small business commercial storefronts on the street level. The park was named after WWII Veteran and community leader, William (Bill) F. Rainey, who led an advocacy effort in the 1980s to have the City convert vacant lots and tenement houses to a public park. Today, the park is used for sports, recreation, and community gatherings and continues to see stewardship from active community groups. The case area is accessible via the above ground 2 and 5 trains, as well as the below ground 6 train, which has experienced waterfall-like flooding during past rain events.

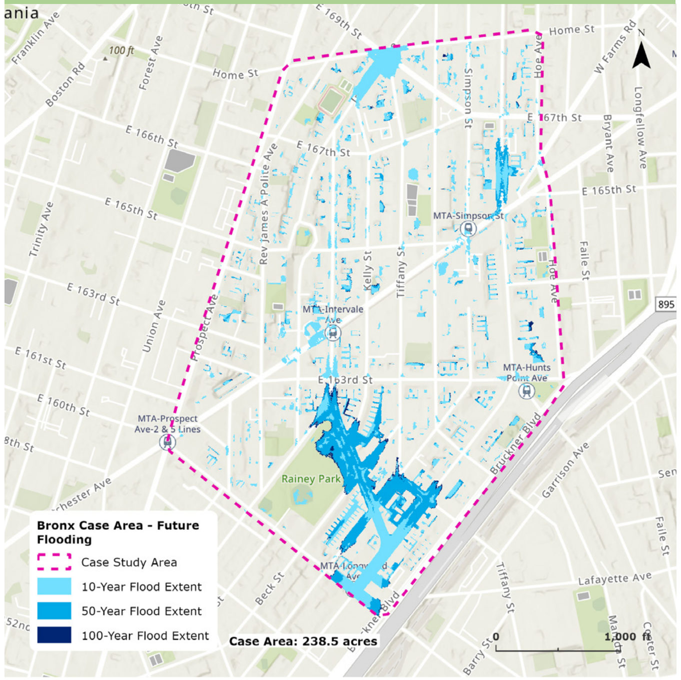
Flooding in the case area: Rainey Park, The Bronx

Flowlines



Flooding (2023)

Flood Projection (2050)



Flow direction

The northern most part of the case area conveys excess stormwater northward and out of the area around Intervale Ave. Stormwater runoff from the rest of the case area flows southward and exits at Southern Blvd.

Flood model results

Overall, the model shows minor flooding throughout the case area, starting from a 5-10-year event. The largest amount of flooding occur in the northern part of the case area, around Intervale Ave and Home Street. On Southern Blvd, two major flood areas can be seen: one in the middle of the case area and another in the southern part.

53 people/acre

Population density

The overall aim is to use proposed Central Detention areas to capture the stormwater that exceeds the capacity of the drainage system. These Central Detention areas have many co-benefits and low construction & operational costs, such as in parks and school areas. The excess stormwater will be conveyed to these areas on the surface in streets newly designed for this purpose, called Stormwater Conveyance Road. In addition, to lower the peak flow in these streets, smaller scale detention is proposed in Green Stormwater Streets, see plan on the next page.

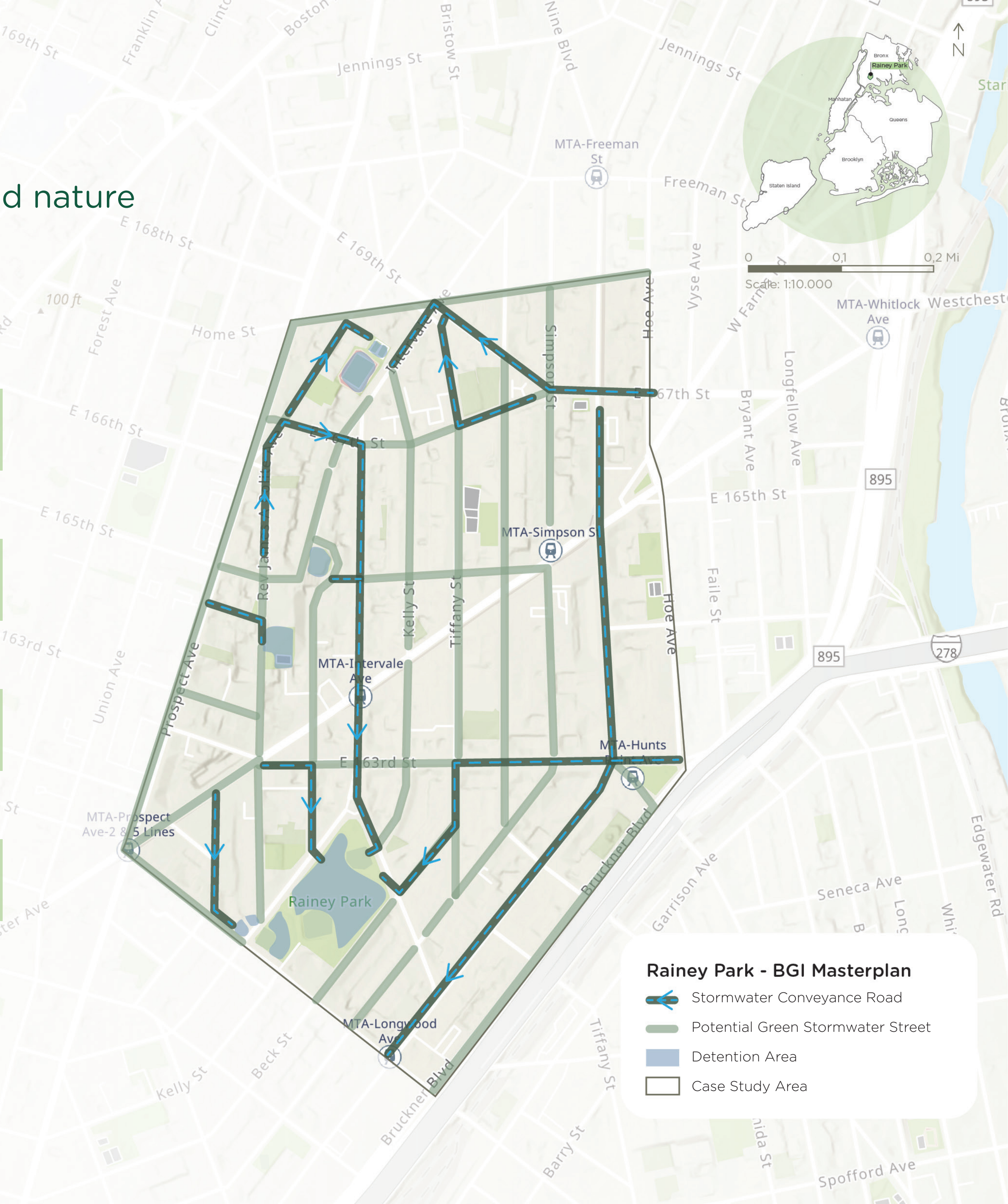
Stormwater Conveyance Roads are proposed in the northern part of this case area to divert excess stormwater to detention sites in sunken sports facilities and open space areas at Metropolitan High School. A Central Detention site is also proposed near the Horseshoe and Stepping Playgrounds.

The central detention site is proposed in Rainey Park. Stormwater Conveyance Roads divert runoff from Longwood to Rainey Park.

	10-year	50-year
Volume managed (mg)	3.98	9.27
Plan cost (million USD)	41.8	93.6
Maintenance per year (million USD)	1.0	2.3
Avoided Expected Annual Damages in 2050	12.7	17.8

Proposed BGI master plan and added nature

Trees planted in streets	290
Trees planted in total	330
New recreational space above 0.3 ha	89,500 ft2
New grass area	8,800 ft2

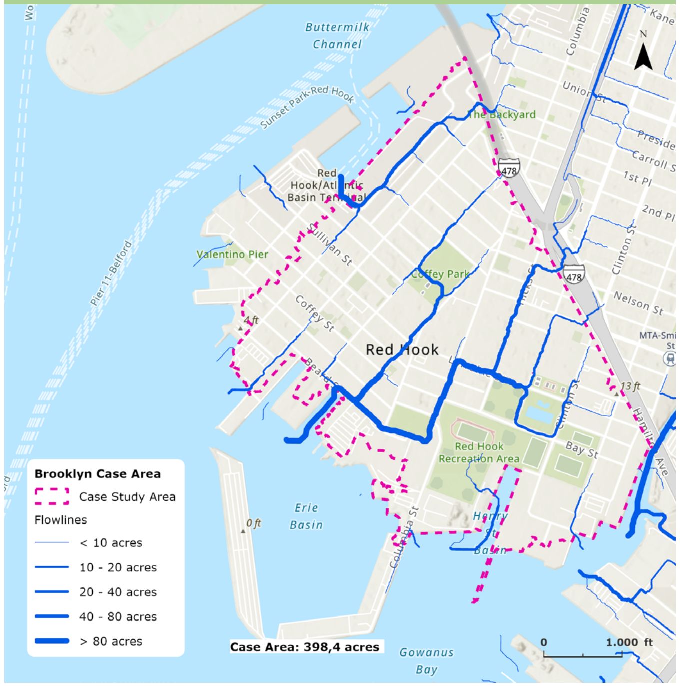


Getting to know the case area: Red Hook, Brooklyn

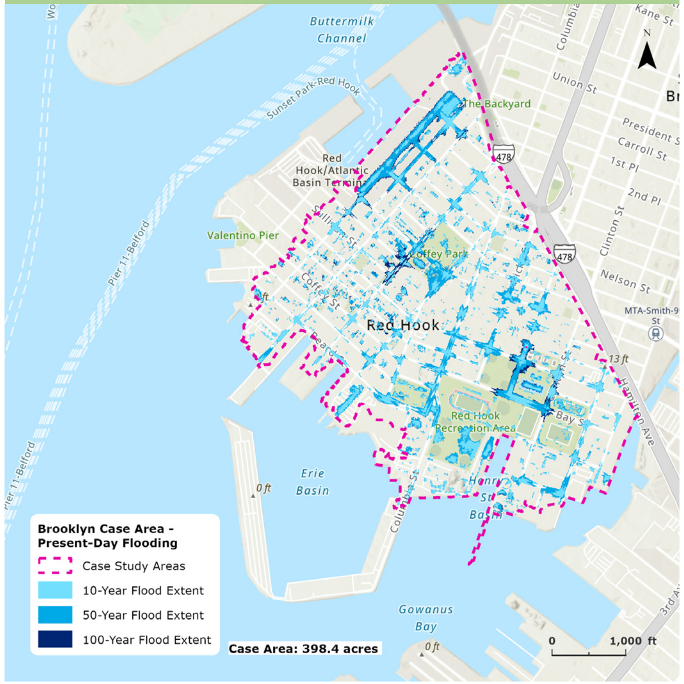
Red Hook is home to approximately 35,000 residents. Once a highly active shipping port community, the neighborhood now has a mix of industrial, commercial, and residential uses, including three NYCHA campuses (Red Hook East, Red Hook West, and Red Hook Houses), a park (Coffey Park), and a number of schools (Red Hook Neighborhood School, Basis Independent Brooklyn Upper School, and K698 South Brooklyn Community High School) and religious institutions (Redemption Church, Red Hook Holiness Church, and Calvary Baptist Church). Despite being battered by Hurricane Sandy in 2012, the neighborhood has experienced a significant influx of new residents over the past decade. The neighborhood sits in the FEMA 100-year flood zone. Planning is underway for The Red Hook Coastal Resiliency Project and the Red Hook Houses Sandy Resiliency and Renewal Program to reduce flood risks from storm surge and sea level rise; however, the neighborhood does not have any plans for stormwater flood mitigation.

Flooding in the case area: Red Hook, Brooklyn

Flowlines



Flooding (2023)



Flood Projection (2050)

Flow direction

There are two overall flowpaths in the case area. The runoff from the northeast area flows south and exits towards Gowanus Bay, the northwest area flows south to the Buttermilk channel west of the area.

Flood model results

Overall, the model shows minor flooding throughout the case area, starting from a 5-10-year event. The largest flooding appears around the center of the case area along Dwight Street, Colombia Street, Henry Street and Richards Street

In the Red Hook case area, Central Detention Areas are proposed in parks, schools, and on NYCHA Grounds. In addition, Cleansing Biotopes (see p.33) are proposed to discharged excess stormwater in areas closer to the waterfront with fewer opportunities to utilize larger open spaces for controlled flooding.

Proposed Stormwater Conveyance Roads lead excess runoff to Red Hook Farms at Wolcott Street, the playground at Patrick F. Daly School, and the Handball Courts in Coffey Park. Also, Stormwater Conveyance Roads are suggested for alleviating flooded areas in the northeastern part of the case area by diverting to Reed Hook sports fields. This stormwater will only flow into carefully designed floodable areas and only during extreme rain events. This can be done without any risk for urban gardens and other existing facilities.

Further, excess runoff from Richards Street, Dwight Street, and Columbia Street, is diverted to green areas and a proposed sunken parking lot at Columbia Street Esplanade. The 10-year event will be managed within the green areas and the 50-year event will overflow to a portion of the parking lot.

The NYCHA Grounds take up most of the central part of the neighborhood with many opportunities for detention. NYCDEP and NYCHA looking into a Blue-Green Infrastructure plan for Red Hook Houses.

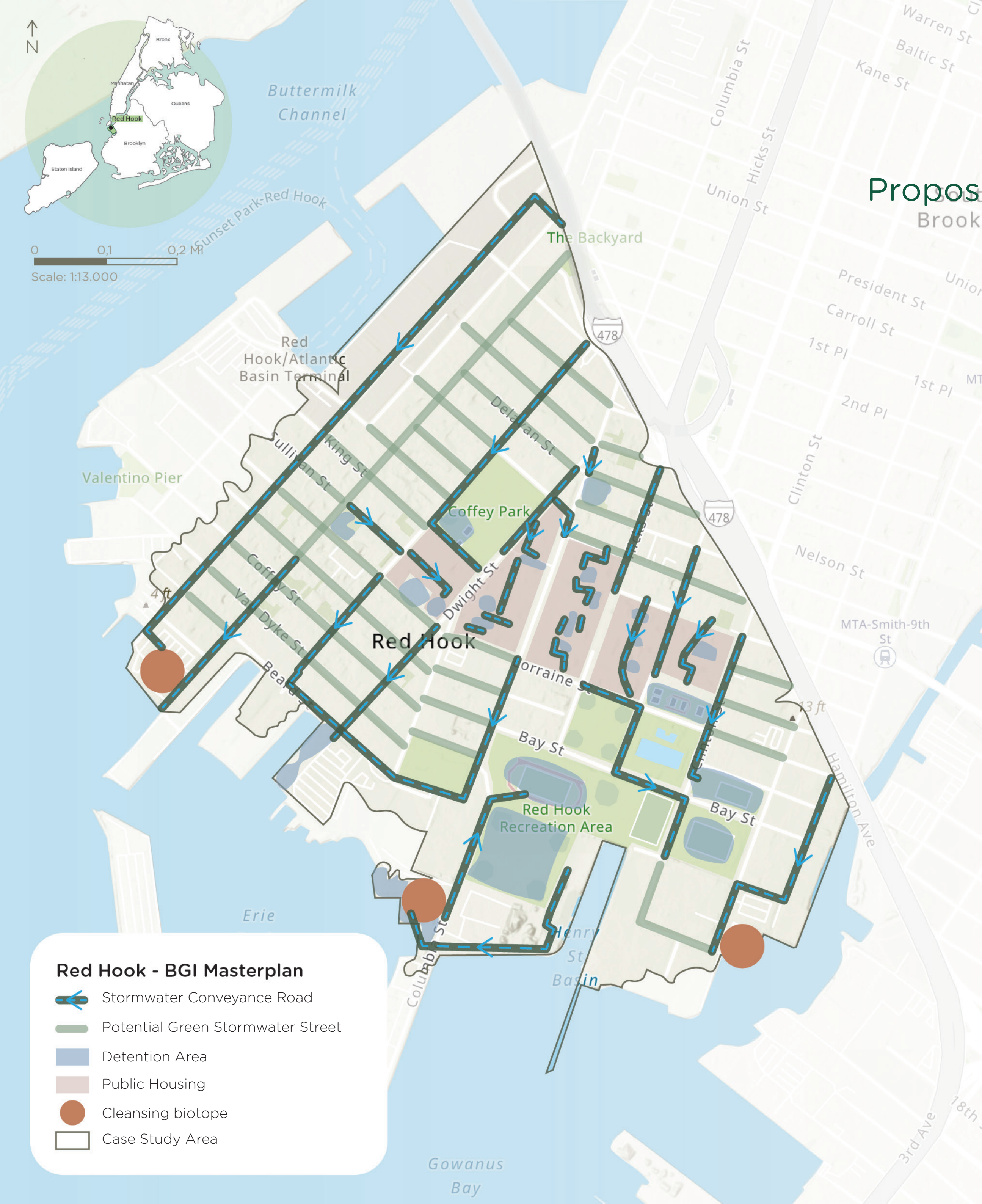
60 people/acre

Population density

	10-year	50-year
Volume managed (mg)	6.65	15.49
Plan cost (million USD)	56.7	102.6
Maintenance per year (million USD)	1.4	2.6
Avoided Expected Annual Damages in 2050	2.6	3.2

For the waterfront areas, three Cleansing Biotopes for stormwater filtration are proposed: at the end of Conover Street, the southeast area at Court Street, and the southern part of the Columbia Street Esplanade. This is in addition to the existing CSO and MS4 outfalls

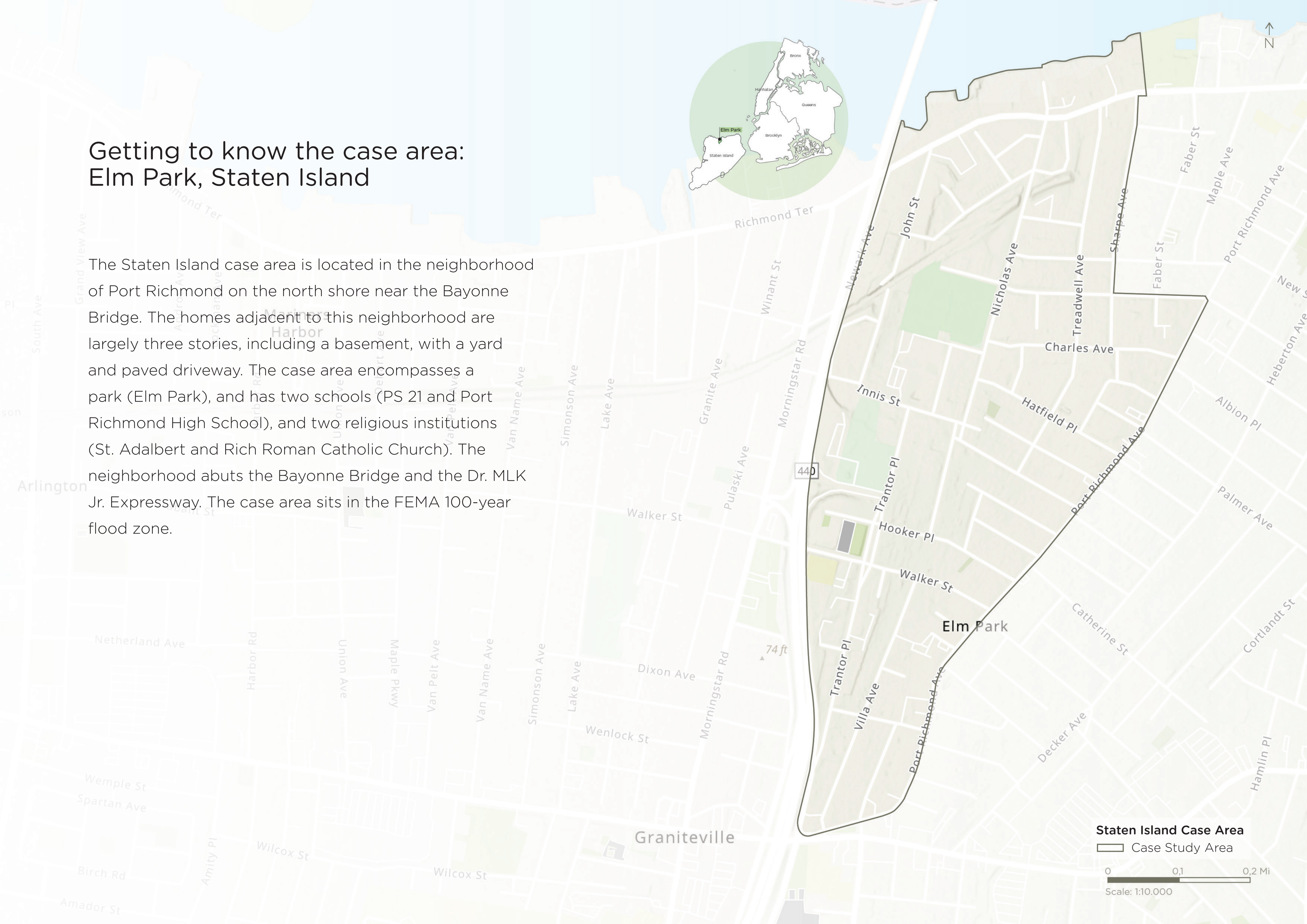
Proposed BGI master plan and added nature



Trees planted in streets	500
Trees planted in total	550
New recreational space above 0.3 ha	66,100 ft2
New grass area	9,700 ft2

Getting to know the case area: Elm Park, Staten Island

The Staten Island case area is located in the neighborhood of Port Richmond on the north shore near the Bayonne Bridge. The homes adjacent to this neighborhood are largely three stories, including a basement, with a yard and paved driveway. The case area encompasses a park (Elm Park), and has two schools (PS 21 and Port Richmond High School), and two religious institutions (St. Adalbert and Rich Roman Catholic Church). The neighborhood abuts the Bayonne Bridge and the Dr. MLK Jr. Expressway. The case area sits in the FEMA 100-year flood zone.



Flooding in the case area: Elm Park, Staten Island

Flowlines

Flooding (2023)

Flood Projection (2050)

Flow direction

There are three overall flow paths in the case area. One going north towards the water at Kill Van Kull from Blackford Ave. The second in the center of the case area flowing towards east at through La Forge Ave and south. The third in the southern part of the case area leading towards the east at Dixon Ave.

Flood model results

Overall, the model shows minor flooding throughout the case area, starting from a 5-10-year event. The majority of which is in the eastern part of the case area, between Burden Ave and Walker street. To the north, close to the water at Kill Van Kull, there are two flood areas, one at Nicholas Ave and the other at Richmond terrace.

The Elm Park case area proposes a combination of Central Detention and discharge via Cleansing Biotopes. Both supplemented using smaller scale upstream detention using Green Stormwater Streets.

Central Detention Areas are proposed at Port Richmond High School to manage excess runoff from the east. Additionally, three detention sites are proposed for Margaret Emery-Elm Park School and the Port Authority property.

Stormwater Conveyance Roads will divert excess runoff to the Central Detention areas and then onward to the proposed Cleansing Biotope. These include Trantor Place and the parks north of Sts. Adalbert & Roch Roman Catholic Church.

For the flood prone areas around Laforge Avenue to the east, no suitable detention sites have been identified within the case area. Consequently, a Stormwater Conveyance Road diverts runoff out of the case area towards the east of Laforge Avenue. In the northern part of the case area Stormwater Conveyance Roads lead water to a small filtration site at Kill Van Kull before discharge to the harbor.

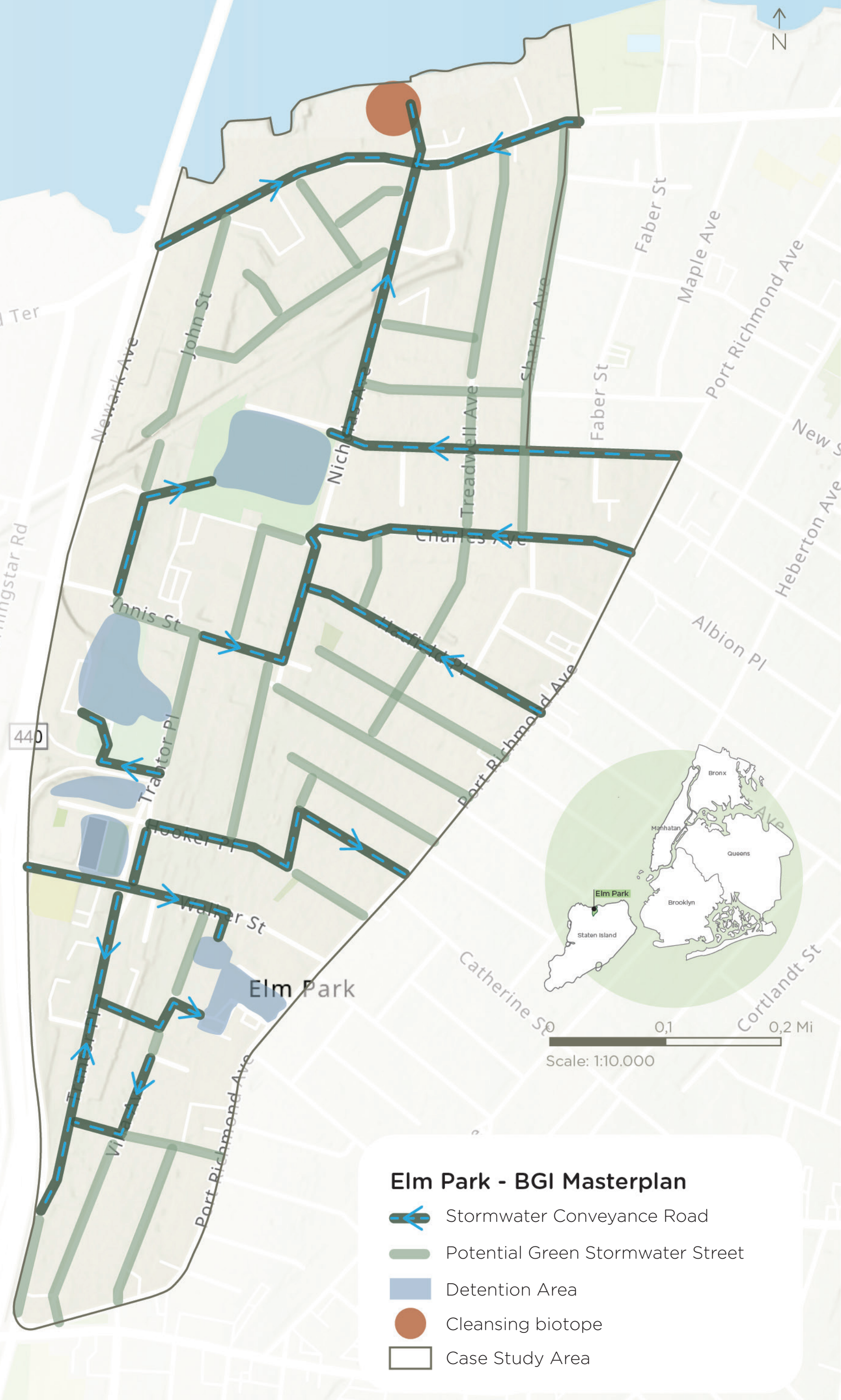
13 people/acre

Population density

	10-year	50-year
Volume managed (mg)	3.68	8.56
Plan cost (million USD)	33	62.4
Maintenance per year (million USD)	0.8	1.6
Avoided Expected Annual Damages in 2050	2.9	3.4

Proposed BGI master plan and added nature

Trees planted in streets	240
Trees planted in total	300
New recreational space above 0.3 ha	98,200 ft2
New grass area	6,000 ft2



Elm Park - BGI Masterplan

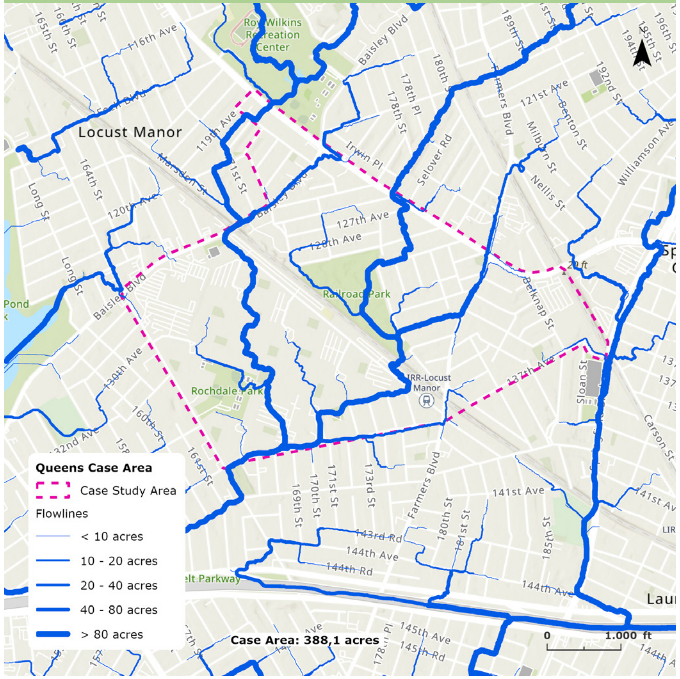
- Stormwater Conveyance Road
- Potential Green Stormwater Street
- Detention Area
- Cleansing biotope
- Case Study Area

Getting to know the case area: Railroad Park, Queens

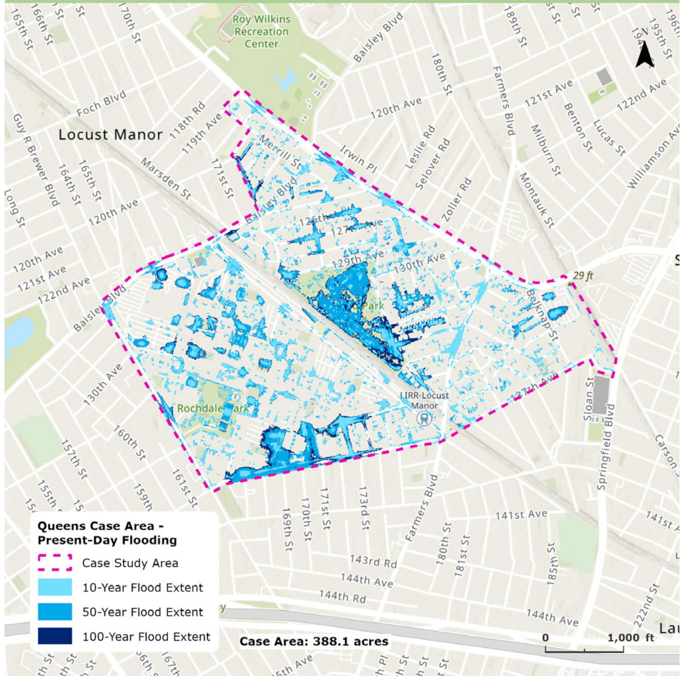
The Queens case area sits in the neighborhood of Rochdale in Jamaica. Home to a diverse population, this area comprises a mix of single family and multi-family homes. The case area is divided in the middle by a LIRR train line that runs parallel to Bedell Street. North of Bedell Street, the homes are largely three stories, including basements and have private lawns. South of Bedell Street is Rochdale Village, a Mitchell-Lama Housing Cooperative, with multi-story buildings, Rochdale Park, and two malls. The case area is home to one religious institution (The Kingdom Hall of Jehovah's Witnesses) and one school (The Thurgood Marshall Magnet School of Multimedia and Communications). Railroad Park (Gwen Ifill Park) sits in the middle of the case area, with 16 acres of park land. Additionally, the area is within a FEMA Flood Zone.

Flooding in the case area: Railroad Park, Queens

Flowlines



Flooding (2023)



Flood Projection (2050)

Flow direction

The case area is bisected by a railway from the northwest to the southeast. The predominant overland flow within the area is from north to south, with an exit point located in the southern part of the case area. In the northern section of the case area, the flow follows a northward direction.

Flood model results

Overall, the model show minor flooding throughout the case area, starting from a 5-10-year event. In Particular, the results show several minor floods in the Gwen Ifill Park. To the east of Gwen Ifill Park, there is some larger flooding expected in the residential area between 176th and 178th street. North from the park two big floods are expected at 126th and 128th Ave. In the eastern part, there is a lot of flooding in the public housing area owned by NYCHA, primarily in the green spaces and on the roads.

34 people/acre

Population density

Stormwater Conveyance Roads are proposed in order to divert overland flow from six smaller sub-catchments to detention sites in Gwen Ifill Park.

In addition, due to lack of appropriate space for detention sites and the general topography sloping out of the neighborhood, Stormwater Conveyance Roads are proposed along 137th Ave conveying runoff out of the case area towards a green area in the neighboring catchment.

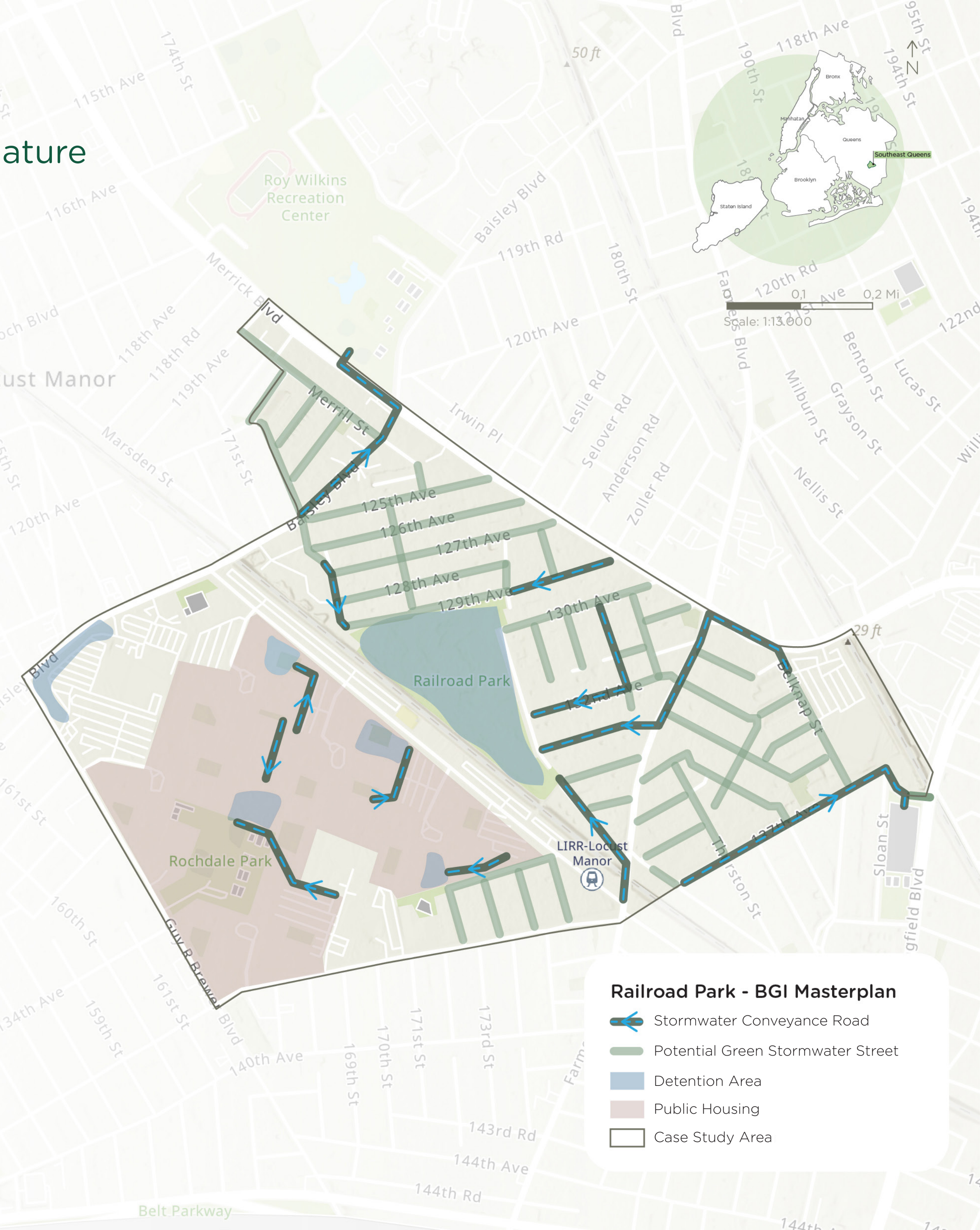
Similarly, a Stormwater Conveyance Roads is proposed at Merrick Blvd conveying runoff out of the case area towards a neighboring park. This intervention has previously been proposed for excess stormwater conveyance in a previous study undertaken by Ramboll for NYCDEP in 2017.

A NYCHA area dominates the western part of the case area. Here ample space is available to manage all stormwater runoff west of the railway in planned Central Detention Areas with high potential for creating co-benefits for area.

	10-year	50-year
Volume managed (mg)	6.43	14.98
Plan cost (million USD)	52.5	104.6
Maintenance per year (million USD)	1.3	2.6
Avoided Expected Annual Damages in 2050	4.0	5.5

Proposed BGI master plan and added nature

Trees planted in streets	250
Trees planted in total	350
New recreational space above 0.3 ha	205,600 ft2
New grass area	15,600 ft2

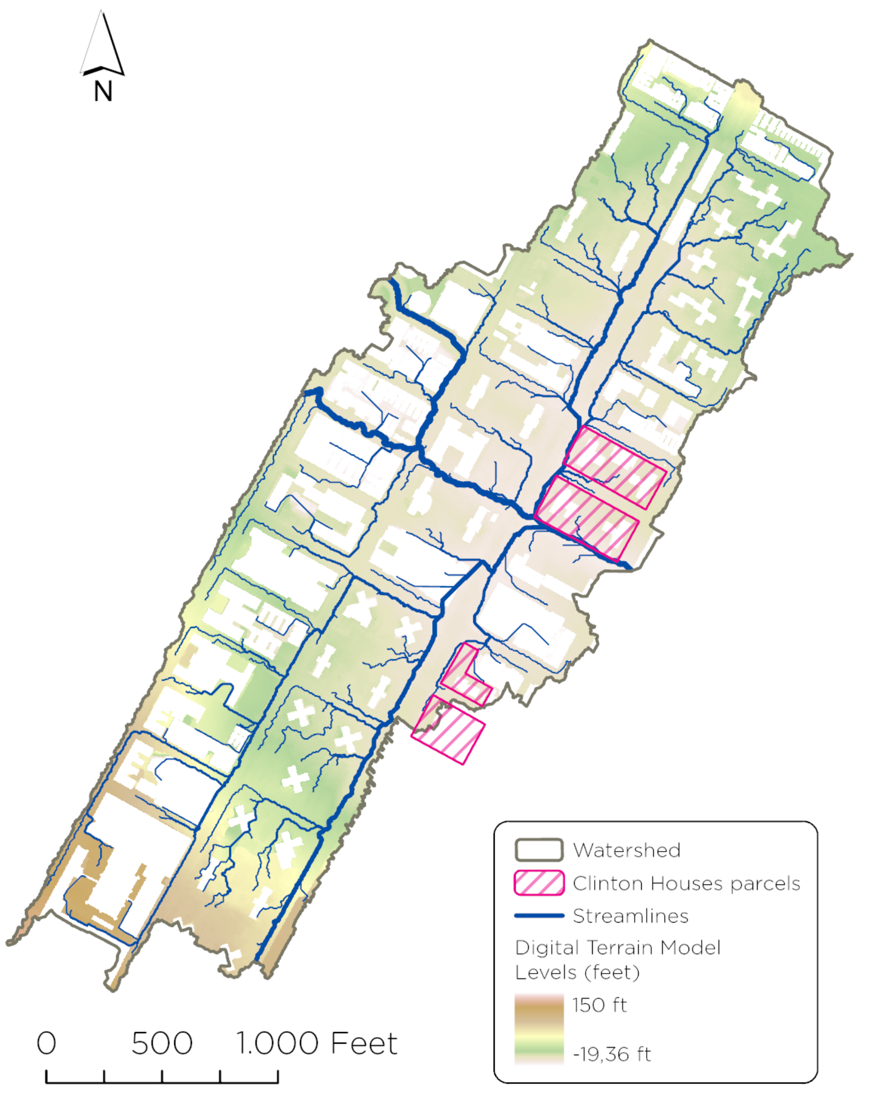


Getting to know the case area: Clinton Houses, Manhattan

Used for validation of applied Capital and operational expenditures (CAPEX/OPEX) in this study.

The Manhattan case area is located in East Harlem, a predominantly lower income neighborhood with the highest concentration of public housing developments (NYCHA) in Manhattan. The case area includes NYCHA's Clinton Houses, three educational institutions, (Success Academy, Amber Charter School East Harlem, and The East Harlem School), and two religious institutions (First Spanish United Methodist Church and Primera Iglesia Bautista Baptist Church). The case area sits in the FEMA 100 year flood zone. In 2019 the City released the East Harlem Resiliency Plan to reduce the risk of stormwater and coastal flooding, integrating parks with stormwater infrastructure. This case area is also one of NYC Department of Environmental Protection's selected locations for a pilot Cloudburst Management strategy.

Topography, catchment and streamlines



The terrain in East Harlem slopes towards East River and is generally flat with no major hills or valleys.

NYCHA Clinton Houses parcels are located where stormwater runoff would naturally flow out of the catchment. Analysis of surface flows on terrain shows that during heavy rain, excess stormwater in the area flows along 108th street adjacent to the NYCHA Clinton Houses parcels. Being located downstream in the catchment makes NYCHA Clinton Houses vulnerable to inland flooding caused by stormwater.

BGI master plan
Manhattan - Clinton houses

The proposed BGI Network for NYCHA Clinton Houses comprises 16 projects, all contributing to stormwater management. These projects collectively form a network of BGI solutions, highlighting stormwater as a visible neighborhood amenity. This network includes various typologies and functions, with preliminary estimates of flooded areas and volumes at this planning stage.

Nine retention areas have been strategically designed to accommodate catchment stormwater. Local retention areas capture and temporarily store runoff from their respective parcels, while central retention areas also receive water from connecting BGI projects. These retention areas are strategically placed within NYCHA campuses to maximize cost-effectiveness and potential co-benefits, such as converting gray areas into multifunctional green spaces, like sunken basketball courts.

Visualization of proposed Cloudburst resiliency master plan for NYCHA Clinton Houses, New York.

Image credit: Ramboll

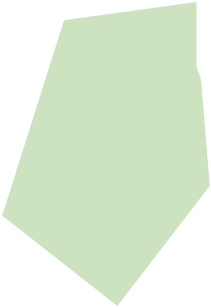
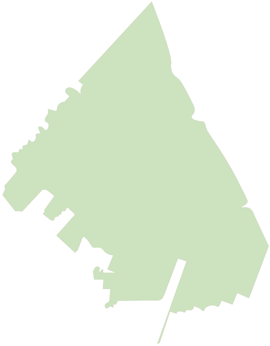
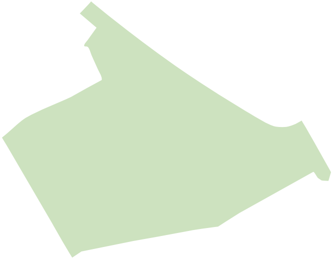
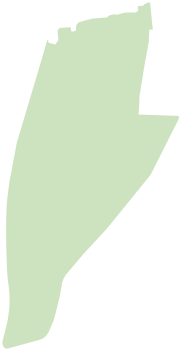
View of basketball court at NYCHA Clinton Houses (Sept. 2020)
Image credit: Ramboll

Rendering of proposed BGI basketball court at NYCHA Clinton Houses
Image credit: Ramboll

Monetized co-benefits by Ramboll's "NBS Value"

Present value in million USD	 Rainey Park	 Red Hook	 Railroad Park	 Elm Park
RECREATION	18.61	11.5	12.5	4.5
AIR QUALITY	0.5	0.9	2.5	0.6
PHYSICAL ACTIVITY	20.6	4.4	9.4	5.1
CARBON STORAGE	0.01	0.02	0.04	0.01
ENERGY SAVINGS	0.2	0.3	0.5	0.1
TRAFFIC SAFETY	6.2	7.5	8.8	5.2

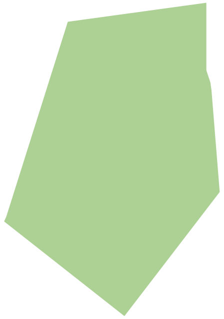
The business case for a 10-year storm in 2050

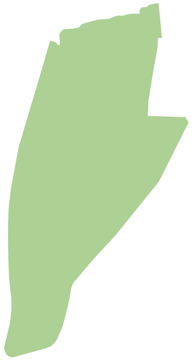





Rainey Park	Red Hook	Railroad Park	Elm Park	(All values except BCR in million USD)
-34	-46.1	-42.7	-26.8	Cost*
90.5	18.0	28.3	20.5	Benefit
45.6	24	33.3	15.1	Co-benefit
102.2	-4.1	33.3	8.8	Net Present Value
4.0	0.91	1.44	1.33	BCR

*The cost prices are high level unit cost based on experience from NYC, DC and other major dense urban areas in US, The costs include: design, planning, supervision & management, construction site, traffic diversions, relocation of utilities, and unforeseeable costs. They also include both the hydraulic function, water quality, and additional planting, street furniture, recreational designs and equipment to unlock co-benefits.

The business case for a 50-year storm in 2050





Rainey Park	Red Hook	Railroad Park	Elm Park	(All values except BCR in million USD)
-76.2	-83.4	-85.1	-50.7	Cost
123.5	22.01	37.7	24	Benefit
45.6	24	33.3	15.1	Co-benefit
93	-37.4	-14.1	-11.6	Net Present Value
2.2	0.55	0.83	0.77	BCR

*The cost prices are high level unit cost based on experience from NYC, DC and other major dense urban areas in US, The costs include: design, planning, supervision & management, construction site, traffic diversions, relocation of utilities, and unforeseeable costs. They also include both the hydraulic function, water quality, and additional planting, street furniture, recreational designs and equipment to unlock co-benefits.

Reflecting on the business cases

Rainey Park
The Bronx

Rainey Park has the best Benefit-Cost Ratio of all proposed case areas for both the 10-year and 50-year BGI Network.

Both the Expected Annual Damages and co-benefits are high compared to the investment cost. This is due to many new recreational areas have been proposed in densely populated neighborhoods including upgrade of existing underutilized green spaces.

This pattern is seen in large portions of Bronx with NYCHA campuses located in flood prone areas.

The study shows that the average Benefit-Cost Ratio is above 1.0 for a 10-year protection level and above 0.75 for a 50-year protection level (0.75 being the threshold for projects in areas with large Climate Justice effects).

The case area, and Queens, is characterized by relatively low avoided Expected Annual Damages but also favorable investment costs and higher than average co-benefits in the central area.

Railroad Park
Queens

Red Hook
Brooklyn

Red Hook has the lowest return of investment across the case areas.

The need for stormwater filtration prior to discharge significantly increases investment costs. The industrial areas along the waterfront reduces the potential for co-benefits. Within the NYCHA campus in Red Hook, and Brooklyn at large, it is possible to increase the level of co-benefits.

The potential, future revitalization of the waterfront would greatly improve the business case overall if done in synergy with BGI.

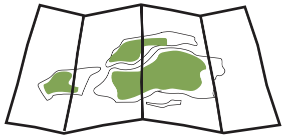
Elm Park shows a positive Benefit-Cost Ratio for the 10-years BGI Network and above 0.75 for a 50-years protection level (0.75 is threshold for projects in areas with large Climate Justice effects). The relatively low Benefit-Cost Ratio is mainly due to lower Expected Annual Damages and challenges to add meaningful additional recreational spaces in an area with relatively high urban green coverage.

Staten Island in general has a fairly low Expected Annual Damages and low co-benefits as the borough already has abundant green spaces and vegetation, where BGI would be suggested.

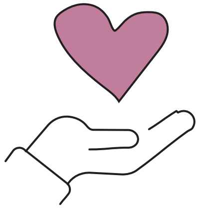
Elm Park
Staten Island

The new business case for New York City

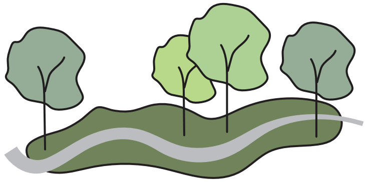
Concluding on the feasibility of Blue-Green Infrastructure in NYC



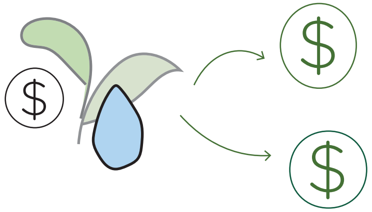
Nature-based, multi-functional BGI provides a positive benefit-cost ratio for the majority of neighborhoods in NYC.



Co-benefits are at the heart of the new business case for inland flood resilience in NYC.

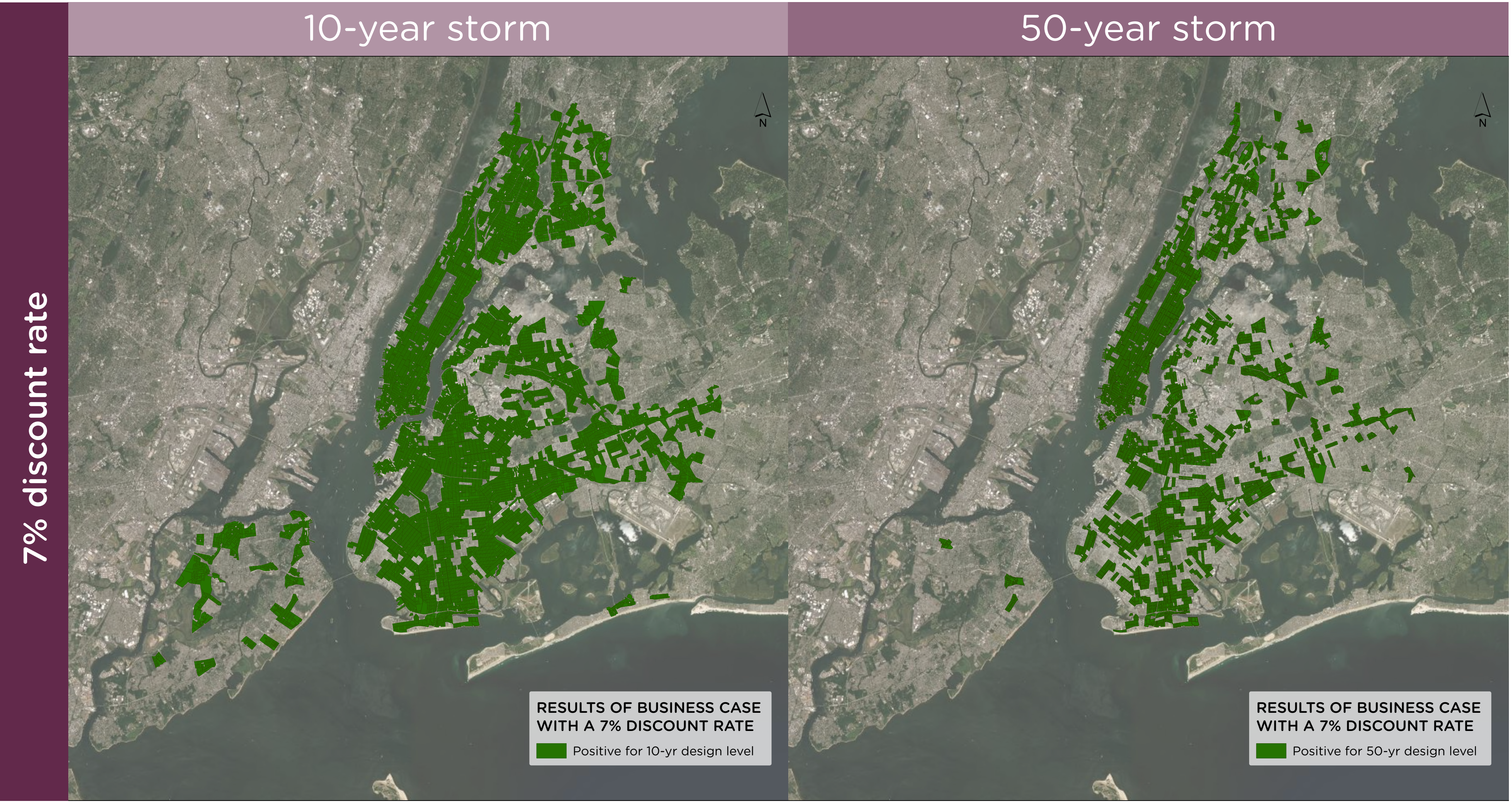


BGI in NYC is most cost-efficient and provides more co-benefits when implemented in open space areas.

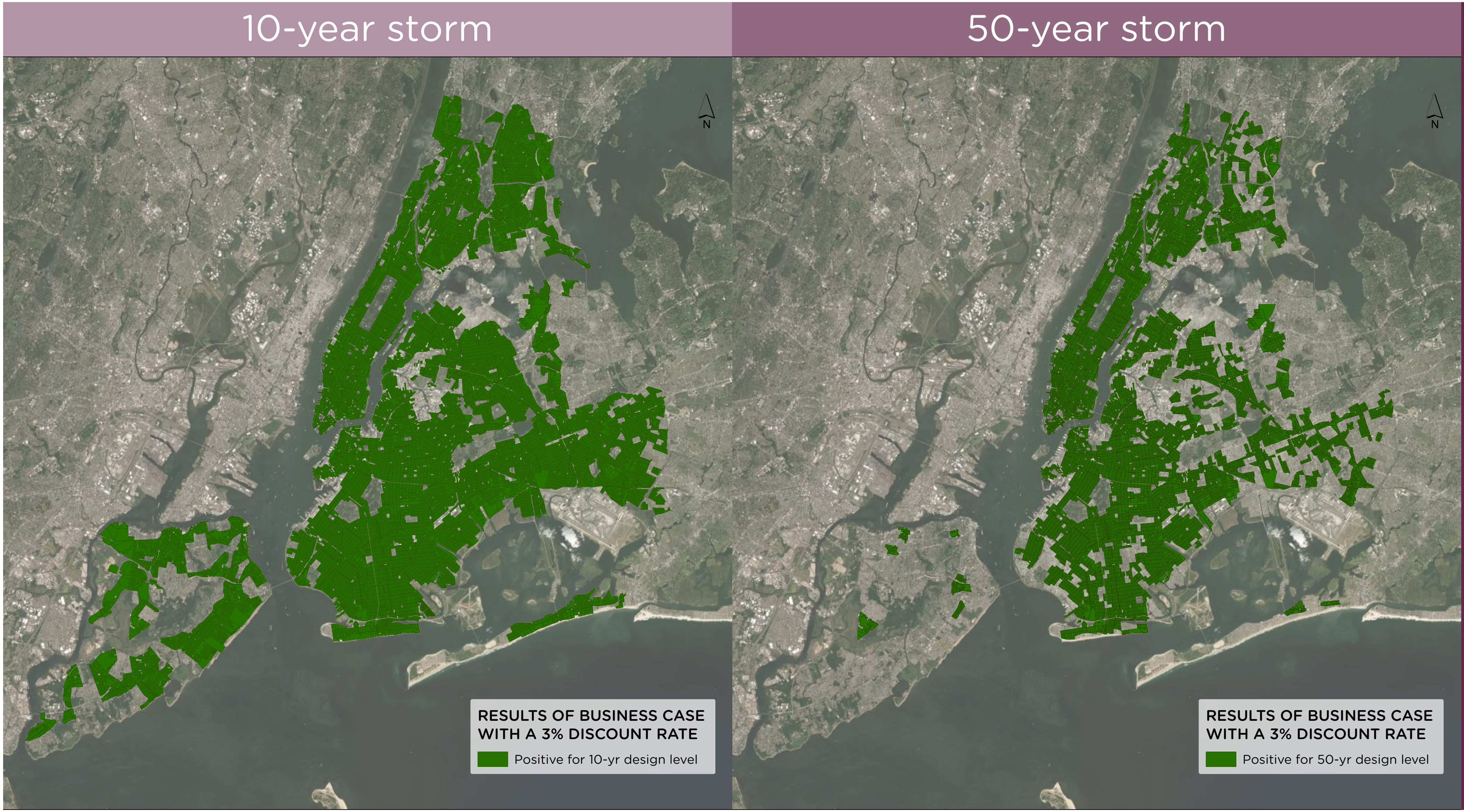


For every $1 invested in a BGI Network design to the 10-year storm in 2050 New York City makes $2 in return.

Citywide areas with positive business cases with 7% discount rate



Citywide areas with positive business cases with 3% discount rate



3% discount rate

Nature-based, multi-functional BGI provides a positive benefit-cost ratio for the majority of neighborhoods in NYC

56%

of area using a 7% discount rate

82%
of area
using a 3%
discount
rate

56% of NYC has a positive BCA for a 10-year storm in 2050

29%

of area using a 7% discount rate

29% of NYC has a positive BCA for a 50-year storm in 2050

50%
of area
using a 3%
discount
rate

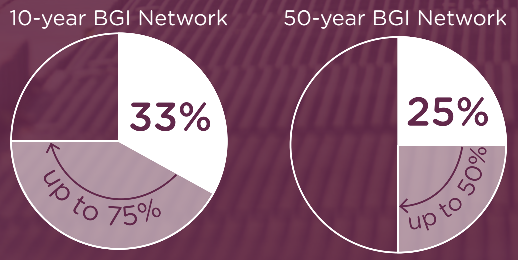
Co-benefits are at the heart of the new business case for inland flood resilience in NYC

Co-benefits make up a minimum 25% of the benefits for the BGI Networks and as much as 75% in some areas.

The co-benefits will for many areas have the opportunity to decide whether the BCR is above or below 1, or in other words, if the project will receive funding or not.

The co-benefits are largely tied to the positive influence nature has on community livelihoods through natural elements such as planting of trees, smaller natural features in roads and new rich, natural areas. To maximize these co-benefits it is essential that we broaden the BGI toolbox to include as much lush, biodiverse, and enriching nature as possible.

THE IMPACT OF CO-BENEFITS



> “Nature-based solutions can provide 37% of the climate mitigation needed between now and 2030 to keep global warming below 2 degrees Celsius - the target of the Paris Agreement. But these interventions currently receive just 3 % of climate funding.”

Erica Gies, Water Always Wins, 2022

Rifle Range Nature Park Singapore

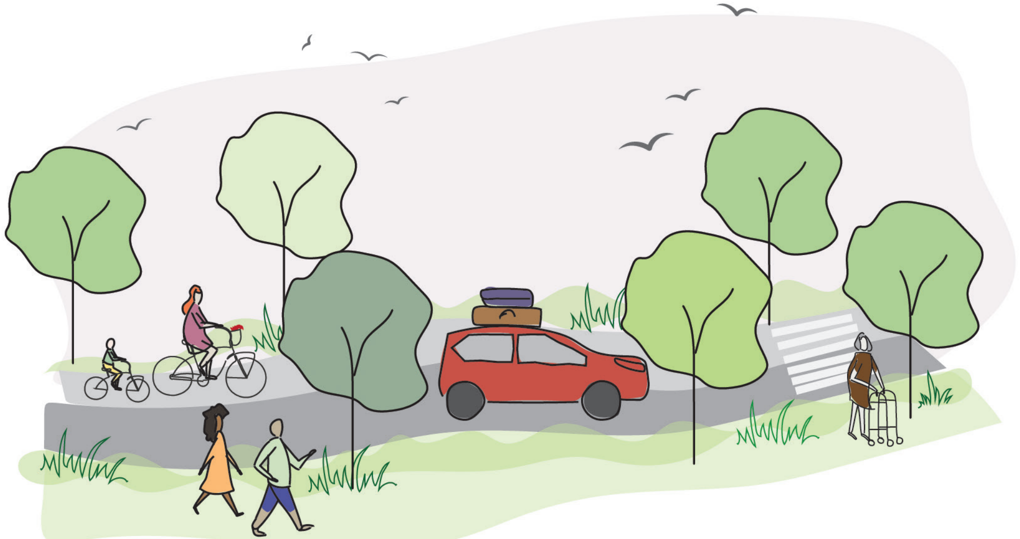
Image credit: Finbarr Fallon

Henning Larsen, part of Ramboll, was commissioned to enhance and protect ecological habitats within a 66ha buffer abutting Bukit Timah Nature Reserve. With more than 7km of trails, boardwalks and a freshwater wetland located in a former quarry, it is also home to a rich variety of plants and over 300 species of wildlife. The 31m tall Colugo Deck above the cliff took inspiration from the flying Sunda Colugo, where visitors can enjoy the one-of-a-kind panoramic forest view over the Quarry Wetland.

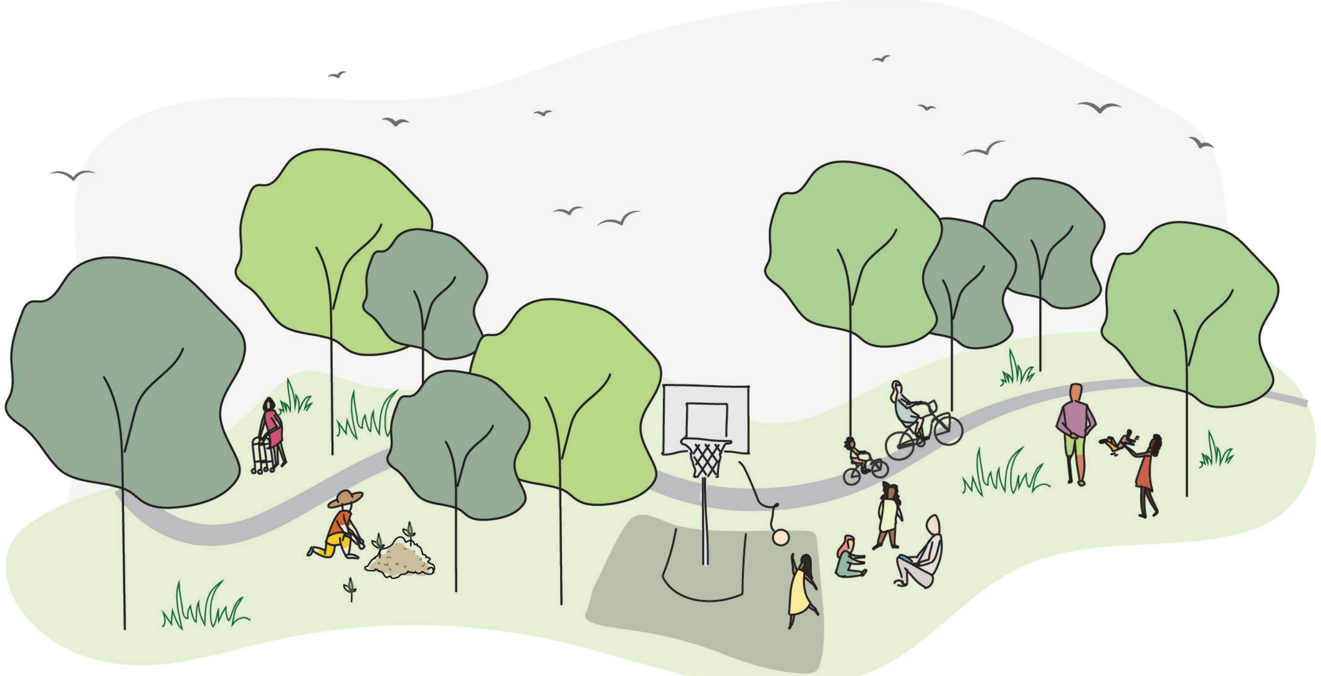
BGI in NYC is most cost-efficient and provides more co-benefits when implemented in open space areas

BGI implementation in parks, plazas, and campuses, whether public or private, is 2-3 times more cost-effective than in streets. This cost difference arises from the limited space available in streets for accommodating increased stormwater volumes, coupled with higher construction expenses for streetscape modifications, particularly concerning underground utilities.

Moreover, the cost estimation for BGI in parks and plazas encompasses enhancements such as new natural areas, recreational facilities, playgrounds, extensive landscaping, and other improvements that provide long-term value to New Yorkers every day. These enhancements are not feasible within streetscapes due to space limitations.

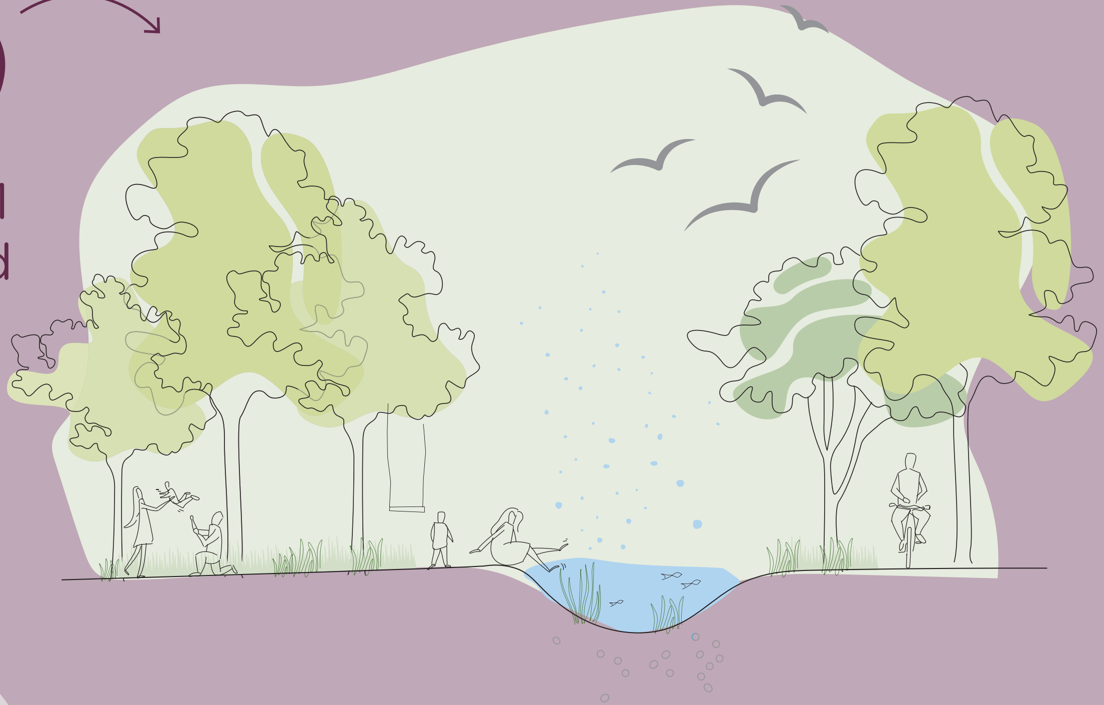


Storage in Right of Way: 18 - 23 USD/gallon



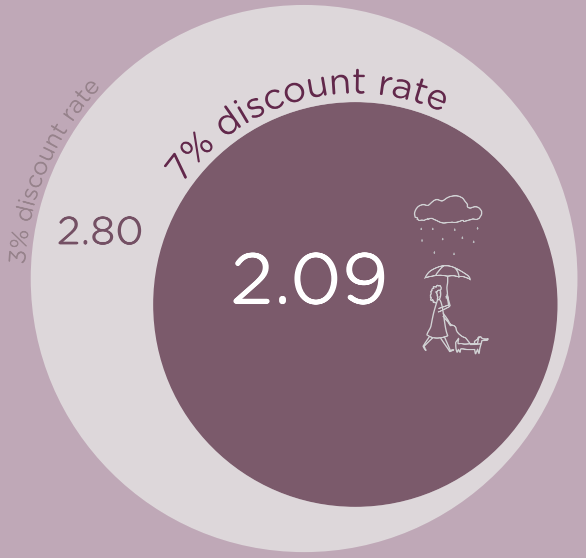
Storage in open space: 7 - 14 USD/gallon

every $1
invested



makes $2
in return

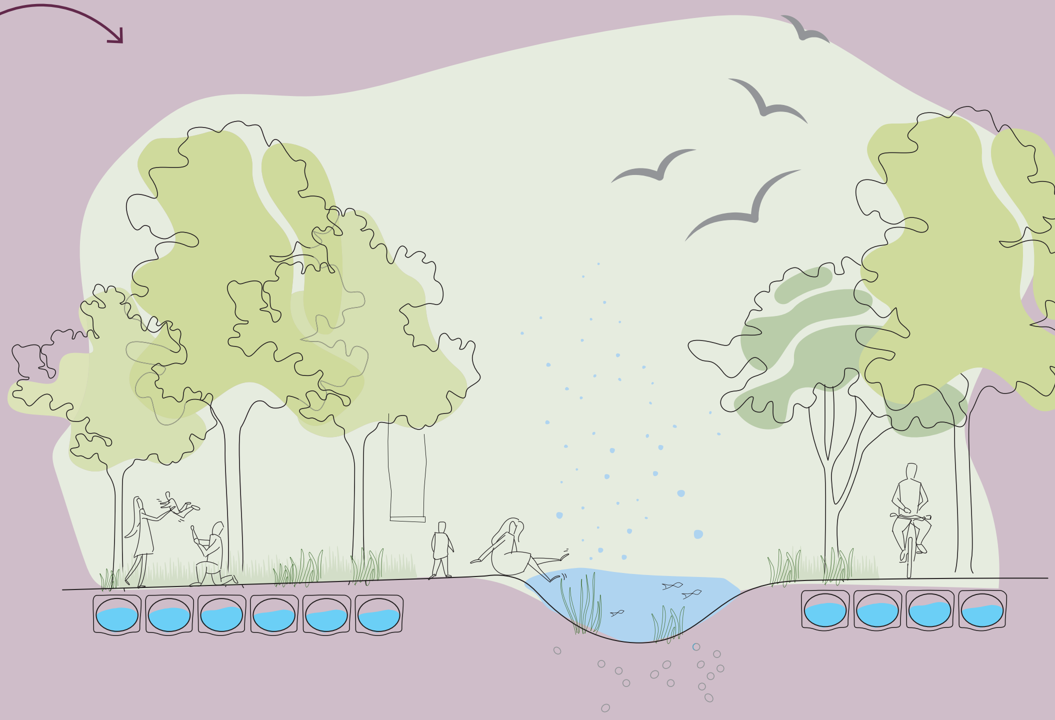
BCR for the 10-year storm



The upscaled citywide benefit-cost ratio shows that: for **every $1 invested** in a BGI Network design to the 10-year storm in 2050 New York City **makes $2.09 in return**

$

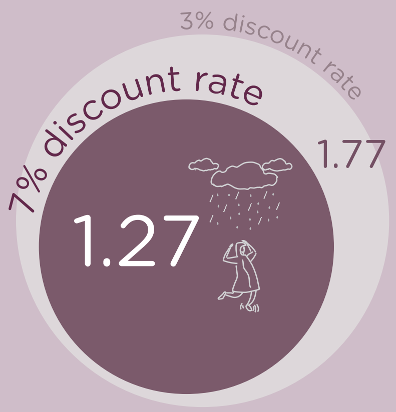
every $1
invested



$

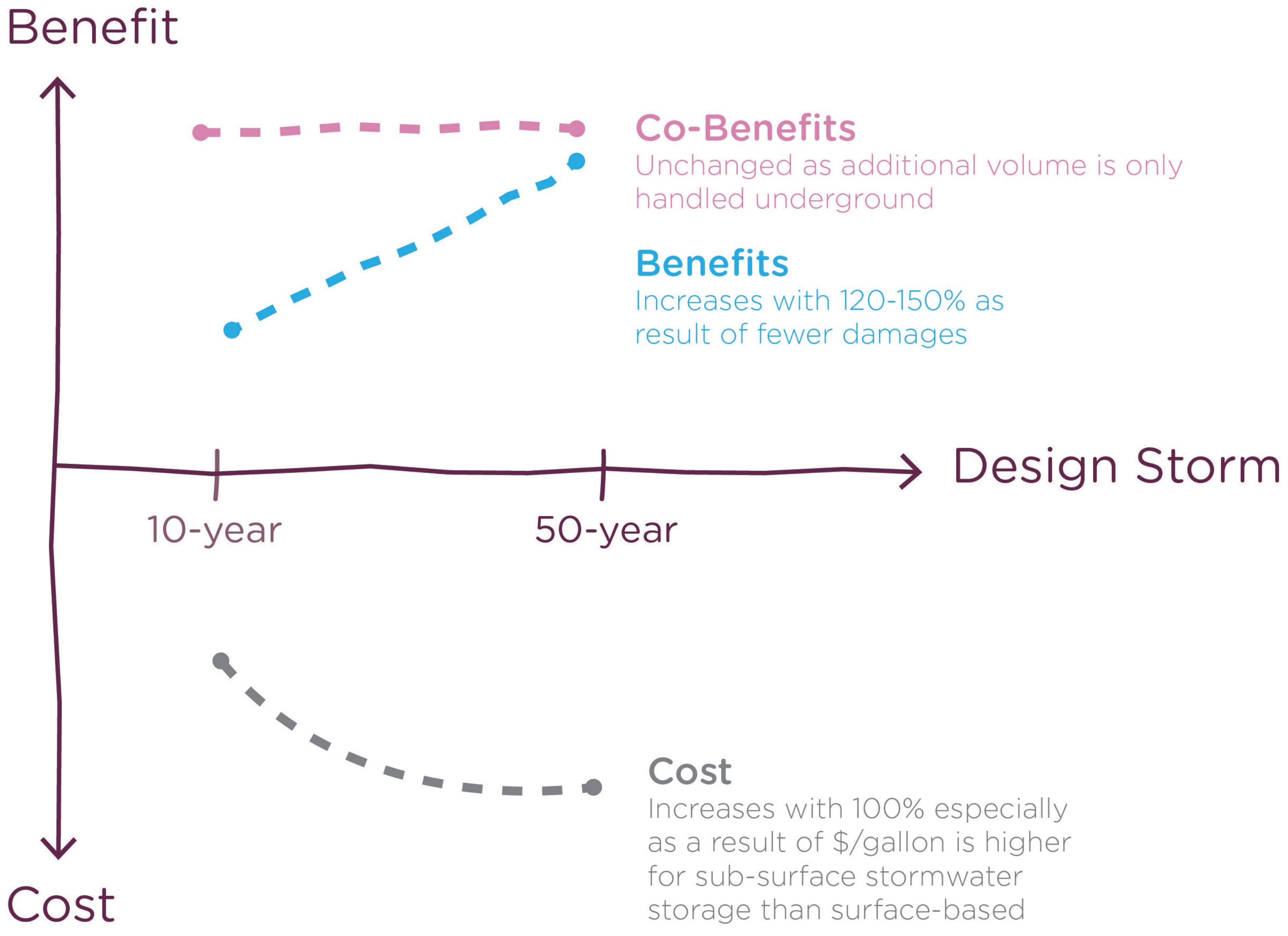
makes $1
in return

BCR for the 50-year storm



The upscaled citywide benefit-cost ratio shows that: for **every $1 invested** in a BGI Network design to the 50-year storm in 2050 New York City **makes $1.27 in return**

Moving from a 10-year to a 50-year design storm in 2050



Co-Benefits
Unchanged as additional volume is only handled underground

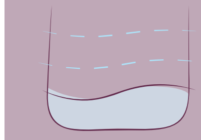
Benefits
Increases with 120-150% as result of fewer damages

Cost
Increases with 100% especially as a result of $/gallon is higher for sub-surface stormwater storage than surface-based

Changing the business case

By up-sizing the 10-year BGI Network plan to handle a 50-year storm in 2050 the additional storage capacity is largely found underground. Therefore the costs and benefits increase but co-benefits stay largely unchanged.

If the 50-year BGI Network plan included additional open space improvements the co-benefits would increase significantly.



The upscaled citywide impact

COST

The total cost of the upscaled BGI Network in present values amounts to:

BENEFITS

In the upscaled BGI Network the total avoided annual damages amounts to:

	COST	BENEFITS
10-year design storm	23,500 million USD	15,000 million USD
50-year design storm	47,000 million USD	22,500 million USD

The upscaled
BGI Network will add

CO-BENEFITS

1,100 acres
of new recreational space

151,000
more trees
across the city

1,000 acres
of revitalized
green space

The total present value of the co-benefits upscaled citywide is estimated to

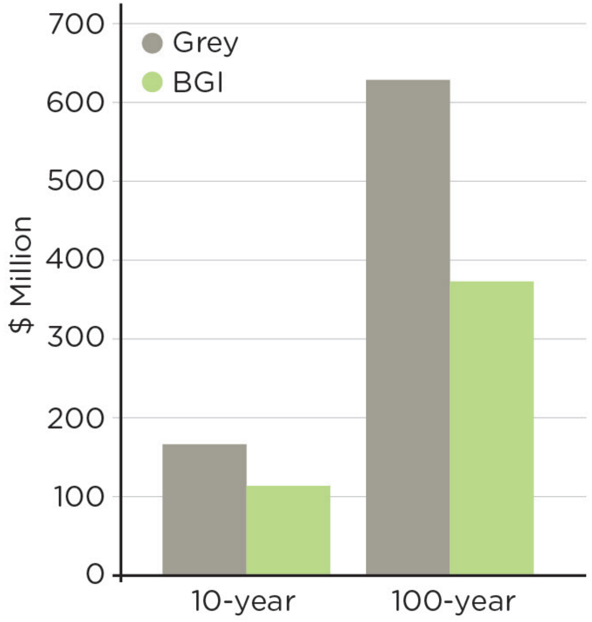
19,500 million USD

Community co-benefits

A conservative business case for citywide BGI

Previous Blue Green Infrastructure (or cloudburst) projects in Copenhagen and NYC show that implementing a BGI network to mitigate climate risk is close to half the cost of addressing similar risk through traditional gray solutions only.

TOTAL CAPITAL COSTS



* The graphical representation is derived from the "Cloudburst Resiliency Planning Study - Executive Summary," a publication by the New York City Department of Environmental Protection in January 2017. The study was prepared by Ramboll A/S.

In preparing the citywide BCA for NYC, the following **5** assumptions represent factors that, if considered, would all contribute positively to the business case. This underscores the conservative nature of this study's business case, as these effects have not yet been factored in:

1. Projects are assumed implemented in isolation. In reality, projects are implemented in synergy with other planned capital projects potentially reducing capital costs by up to 30-50%.

2. Many cities are facing an increase in regulated service levels (capacity) for their sewer systems to meet current or future climate conditions. Such regulation would require service providers to enlarge the capacity of the existing sewer system. Potential savings can be up to 15% of the BGI network cost. These savings are not accounted for.

3. Tailoring generalized typologies to the local context, topographic conditions, community priorities, and location in the catchment has a tendency to lower implementation costs and increase community co-benefits through the increased synergistic affects.

4. Today risk assessments do not include adequate aspects of climate justice and social vulnerability. These aspects are often included through qualitative considerations or indices for comparison. However, these aspects need to gain the same (or more) weight as tangible, quantifiable aspects of climate risk (such as property damage and loss, loss of production, etc.). Including these intangible aspects in the climate risk assessment would greatly increase the "benefit" side of the business case for the people who need it the most.

5. Lastly, the BGI master plans prepared as part of this study include natural cleansing before discharge to the receiving waters to reduce overall loads on wastewater treatment plants and to improve overall water quality. These co-benefits are not monetized in the BCA. Similarly, the monetized savings on the treatment plants are not included (operation and upgrade savings at WWTPs are significant in other cases.)

Reflections and recommendations

How should you use the findings from this study

The findings provide an indication of the overall feasibility of BGI in NYC at typology level, case area level, and city level.

The findings also illustrate the various factors that affect the feasibility of applying BGI for cloudburst resilience. The conclusions of this study can be replicated to the majority of NYC.

The findings from this study are based on a upscaling. We recommend site-specific analysis in combination with social vulnerability to strengthen the contextual aspects of these conclusions.

Identifying suitable next steps for citywide inland flood resilience

Document BGI maintenance

Evaluate and pilot maintenance models that create local jobs and share responsibility with government agencies.

Prioritize co-benefits

Develop catalogue of BGI typologies for NYC that maximize community benefits. A next-generation BGI toolbox is needed to unlock the economic savings from co-benefits.

Define citywide protection level

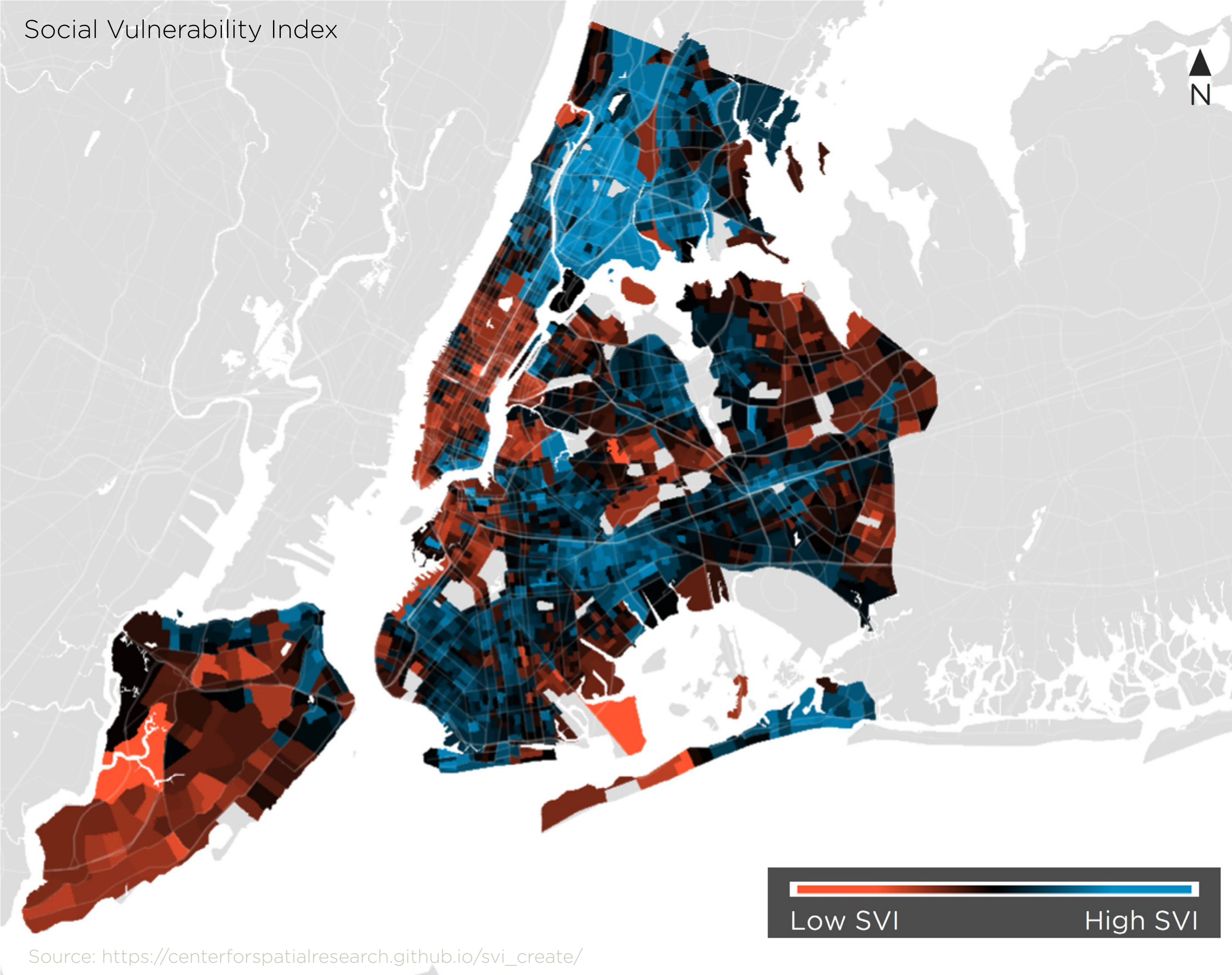
Define methodology for levels of protection for NYC, including acceptable level of risk, and return periods.

Prioritize cloudburst pathway

Develop a transparent prioritization of neighborhoods for cloudburst master planning, beginning with those who have the highest social and physical risk with a +1.0 Benefit-Cost Ratio.

Include social vulnerability

Ensure prioritization of social vulnerability and community resilience, including aspects of socio-economic status, demography, minority status, housing type, gender, etc. Similar factors can greatly influence the co-benefit side of the business case if addressed through the design process and proposal.



Source: https://centerforspatialresearch.github.io/svi_create/

Resources

PUBLICATIONS

NYC's resources for addressing the rising frequency and intensity of heavy rainfall is constantly expanding:

- PlaNYC (2023)

  The City committed to implementing a multilayered strategy for both inland and coastal flooding.

- Rainfall Ready Action Plan (2022)

  Outlines shared responsibilities New Yorkers and City government can do to combat intense storms together – today.

- New Normal (2021)

  A landmark report that provides NYC with a blueprint to prepare for and respond to extreme weather.

- NYC Stormwater Resiliency Plan (2021)

  Helping New Yorkers understand and manage vulnerabilities from extreme rain.

- Climate Resiliency Design Guidelines (2020)

  Design guidelines to integrate forward-looking climate data into the design of City capital projects.

USEFUL LINKS

- NYC Cloudburst Website:

  https://www.nyc.gov/site/dep/environment/cloudburst.page

- NYC Recent press releases

  https://www.nyc.gov/office-of-the-mayor/news.page

  https://www.nyc.gov/office-of-the-mayor/news/023-23/mayor-adams-construction-new-cloudburst-resiliency-projects-better-manage-intense

- NYC Stormwater Flood Maps

  https://experience.arcgis.com/experience/6f4cc60710dc433585790cd2b4b5dd0e

- NYC Flood Hazard Mapper for Coastal Risk

  https://dcp.maps.arcgis.com/apps/webappviewer/index.html?id=1c37d271fba14163bbb520517153d6d5

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