LIVING WITH WATER:

LESSONS FROM
SINGAPORE AND
ROTTERDAM

Living with Water: Lessons from Singapore and Rotterdam documents the journey of two unique cities, Singapore and Rotterdam—one with too little water, and the other with too much water—in adapting to future climate change impacts. While the social, cultural, and physical nature of these cities could not be more different, *Living with Water: Lessons from Singapore and Rotterdam* captures key principles, insights and innovative solutions that threads through their respective adaptation strategies as they build for an uncertain future of sea level rise and intense rainfall.

CENTRE for LiveableCities SINGAPORE

ROTTERDAM WEATHER WISE

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About the Centre for Liveable Cities

Set up in 2008 by the Ministry of National Development and the Ministry of the Environment and Water Resources, the Centre for Liveable Cities (CLC) has as its mission to distil, create and share knowledge on liveable and sustainable cities. CLC's work spans three main areas: Research, Capability Development, Advisory and Knowledge Platforms. Through these activities, CLC hopes to provide urban leaders and practitioners with the knowledge and support needed to make our cities better. www.clc.gov.sg.

CENTRE for LiveableCities SINGAPORE

CLC is a division of MND SINGAPORE

About the Rotterdam Office of Climate Adaptation

The Rotterdam Office of Climate Adaptation is a programme office under the Rotterdam city government's urban management department. The office is formerly known as the Rotterdam Climate Initiative which was set up in 2008 by the Rotterdam City Council to reduce the city's carbon emissions. Together with partners such as the Port of Rotterdam Authority, Dutch Water Boards, businesses and Rotterdam citizens, the Rotterdam Office of Climate Adaptation works to enhance Rotterdam's efforts in sustainability and climate change adaptation. At the city level, Rotterdam's efforts on climate adaptation are guided by the Rotterdam Climate Proof (RCP) Programme (2008), Rotterdam Adaptation Strategy (2013) and Rotterdam Weatherwise Programme which started in 2018. Rotterdam aims to become a fully climate-proof city by 2025.

ROTTERDAM WEATHER WISE

City of Rotterdam

FOREWORD BY MINISTER FOR NATIONAL DEVELOPMENT AND SECOND MINISTER FOR FINANCE, SINGAPORE

As a low-lying, island city-state, climate change poses an existential threat to Singapore.

We must be ready for the challenges climate change will bring – there is no other way.

Singapore is now 54 years old, and we hope to be around for another century and beyond. We have studied, developed short and long-term plans, and implemented actions to safeguard the existence of our nation – and we have done this at various scales. *Living with Water* captures these actions.

We have not done this alone. We have learnt from our friends in the Netherlands, and are piloting our first polder development on one of our islands, with a dike around the area to guard against rising sea levels. We have adopted and contextualised international best practices in urban water management to beautify our waterways and encourage citizens to embrace water and live with it. We have also integrated water sensitive urban design features into our urban environment.

Climate change will also challenge global access to critical resources such as water. This is why Singapore is continually looking at ways to strengthen its water resiliency, especially through innovation and new technologies.

While we have achieved much to build a climate resilient city, our efforts must be ongoing. Climate change is a multi-generational challenge that demands progressive investments now and in the future. The results you see today hinge on the combined efforts of governments and communities everywhere. It requires learning from each other to reach the best possible solution efficiently.

This is what we strive for in our partnership between Singapore and Rotterdam. We believe we can overcome the challenges climate change poses, if we collaborate, take action and forge a resilient and sustainable path together.

Lawrence Wong
Minister for National Development and Second Minister for Finance, Singapore

FOREWORD BY MAYOR OF ROTTERDAM

The Netherlands is known for its temperate sea climate. In general, this means cool summers and cool winters. The summer of 2018 was extremely hot and dry by Dutch standards. And this summer, in July 2019, the country recorded its highest-ever temperature of 39.2 degrees Celsius, which reminded me of my youth in Morocco. Are these freak incidents or are we at the beginning of a period of time that climate change, as such an undisputed occurrence, increasingly shows its effects?

Of course, the Netherlands has for centuries gained experience in everything related to water management, from the reclaiming of land (our polders) to our system of dikes and waterways. In 2001, Rotterdam launched its first urban water management plan to prepare us for possible climate change.

The excessive amount of water has always been the main problem in our delta city. About 85% of Rotterdam lies below sea level. In addition, we are now also experiencing the effects of urban heat and drought.

Nowadays, we prepare the city, businesses and residents for extreme weather events like heavy rainfall, rising sea levels and heat waves. Rotterdam is mostly living with the water instead of fighting against it. We believe in the new opportunities these big challenges are creating such as more jobs and improvement of the public space.

This means we must innovate and continuously reinvent ourselves. The most important switch we make as a city, is working more closely with our citizens and other organisations to become climate-proof. This is logical as 60% of our city is private property.

In our latest climate adaptation strategy, ‘Rotterdam Weather Wise’, we aim for as much collaboration and participation as possible. Together with the citizens we can make Rotterdam more beautiful, livable, greener and at the same time climate proof.

But I know we are not alone in this transition. Cities all around the world are dealing more than ever with the effects of climate change. The ongoing exchange of knowledge and lessons learned is of unprecedented value.

The intense collaboration between Singapore and Rotterdam is of great significance. Attending the World Cities Summit in Singapore is always a great opportunity to exchange knowledge and share experiences. Sharing best practices as well as discussing what went wrong in pilot projects and finding new solutions makes sharing knowledge between cities so valuable.

Being a part of international networks like C40 and 100 Resilient Cities helps us achieve our goals together. I believe in cities taking action and leading the way towards a sustainable future for everyone.

Ahmed Aboutaleb
Mayor of Rotterdam

PREFACE

Singapore and Rotterdam have much in common. We are both port cities. Both cities face challenges of water and climate change. There has been much knowledge sharing and exchange at all levels. The Mayor of Rotterdam, Ahmed Aboutaleb, is a friend to Singapore, and many Singapore Ministers and our President have visited the Netherlands and Rotterdam. The Centre for Liveable Cities' current partnership with the Rotterdam Office of Climate Adaptation is continuing that effort, to learn from each other about climate change adaptation and mitigation measures.

The impacts of climate change are increasingly being felt in both cities. This year's July and August were the driest July and August period in Singapore since rainfall records began in 1869. Similarly, Netherlands has been experiencing a heatwave resulting in record high temperatures, topping 39.2 degrees Celsius on July 25, resulting in a Code Orange extreme temperature warning issued. Echoing our first Prime Minister, the current Prime Minister Lee Hsien Loong shared in his National Day Rally Speech recently, "We should treat climate change defences like we treat the [Singapore Armed Forces]–with utmost seriousness" and "everything else must bend at the knee to safeguard the existence of our island nation". Recently, Rotterdam has taken great strides to tackle climate change and social challenges through their Resilient BoTu neighbourhood–a process of building climate resilience together with people. This is something we can all learn from.

Singapore's approach has always been to develop systemic solutions with a lens of improving liveability and sustainability. We now take on the same systems approach to tackle the challenges arising from climate change. Our climate change policies are coordinated at the highest level, by the Inter-Ministerial Committee on Climate Change, and involves the whole of society: government, industry and the community. Thus far, to address our concerns for rising sea levels and flooding, we have raised the minimum reclamation level from 3 to 4 metres, and future developments are being built at higher platform levels. Second, our "Source-Pathway-Receptor" approach helps to minimise floods by capturing, storing and redirecting stormwater. Third, recognising the

increasing likelihood of drought, we have established NEWater (recycled water) and desalinated water infrastructure which can be used to supplement our water supply. We recognise that these efforts are not easy. Prime Minister Lee, in his National Day Rally speech said that it might cost S$100 billion over 100 years to protect ourselves against rising sea levels.

But hard infrastructure is only half of the solution. Raising awareness and action amongst community is the other. As such, we designated 2018 as the Year of Climate Action in Singapore. It raised awareness and called for action amongst the Public, Private and People (3P) sectors. We received over 340,000 climate pledges from individuals, educational institutions and companies. More than 800 climate action events were held, many in partnership with Non-Governmental Organisations (NGOs) and the private sector. The campaign built strong momentum for climate action, and we continue to work with stakeholders to raise awareness and act together to address climate change.

We are honoured to have the opportunity to collaborate with Rotterdam. It has been and continues to be a leader in climate resilience, developing climate solutions together with various sectors. The city hosts the Global Centre for Adaptation, alongside Groningen. We have learnt much from the study visits and exchange lectures, including while participating in C40's Connecting Delta Cities Workshop and the roundtable sharing session in Rotterdam hosted by our counterparts. There, where we learned much about Rotterdam's key water challenges and innovative urban water plazas to address the challenges of increased precipitation. We have had the opportunity to personally visit the offices where the Blue Label project is being developed which will educate and encourage communities to adopt climate change measures. This innovative method of sharing information to spur community action and co-ownership of solutions would be of interest to many coastal cities worldwide as we prepare for a changing climate. Many of these solutions will be on display at our next World Cities Summit and Singapore International Water Week in 2020.

We look forward to more collaborations in the years to come.

Khoo Teng Chye
Executive Director
Centre for Liveable Cities

1. INTRODUCTION

Global challenges, common solutions

According to reports, the global sea level is projected to rise by 0.7 m to 1.2 m in the next two centuries, even if efforts are made to reduce greenhouse gas emissions to net zero in the second half of the century.[1]

For coastal cities, the implications of sea level rise on coastal zones, particularly those which are densely populated, could be drastic. Sea level rise threatens cities from Shanghai to London and entire countries such as the low-lying Maldives and Kiribati. Furthermore, as climate change could lead to more intense and frequent extreme rainfall events, cities are increasingly vulnerable to flooding. As coastal cities, both Rotterdam and Singapore will need to adopt measures to concurrently address both sea level rise and inland flooding.

To achieve this, cities need to take an urban systems approach. Both Singapore and Rotterdam share strong relationships with water–it has been an integral part of planning and building both cities. The Dutch have built Rotterdam in anticipation of too much water, as 26% of the country lies below sea level and 60% is vulnerable to flooding.[2] Singapore, on the other hand, has been built in consideration of having too little water. Since its independence, the country has faced challenges in providing an adequate and reliable water supply for its rapidly expanding population due to polluted waterways and insufficient volumes in water catchments. With the advent of climate change, however, Singapore has also been preparing for a future with more frequent and extreme storm events.

A pivotal episode in Dutch history in regards to coastal flooding was in 1953, when a combination of a high spring tide and a severe European windstorm over the North Sea resulted in water levels reaching 5.6 m above normal sea level in some areas. A total of 187 km of the Dutch coastal defence was damaged and 1,835 deaths were recorded. In the aftermath of the disaster, the Delta Committee was formed to oversee the Delta Works programme, which strengthened the country's coastal defence through an extensive system of dams and storm surge barriers.[3] While the Dutch initially focused on the rapid removal of water, in recent years there has been a shift towards redesigning cities to create more space for water.[4]

While Singapore has not experienced a similar episode, Typhoon Vamei came within 50 km of Singapore in 2001, bringing with it windy and wet conditions.[5] Furthermore, much of the country is generally flat, with 30% of land less than 5 m above the mean sea level.[6] In communicating the risks of climate change and sea level rise on Singapore, Masagos Zulkifli, Minister for the Environment and Water Resources, highlighted the country's vulnerability:

> *In February 2018, high tides caused temporary flooding even without rain. With rising sea levels, we could experience more of such phenomena.*[7]

To this end, Singapore has taken pre-emptive action to protect its coastal areas such as by raising reclamation levels and installing geobags to address coastal erosion.[8, 9] Singapore also faces risks from extreme rainfall events. Since 1980, the number of heavy rain events has been increasing yearly. The annual number of days with hourly maximum rainfall intensity exceeding 40 mm has grown by 1.9 days each decade. Projections until 2100, undertaken for the Second National Climate Change Study by the Centre for Climate Research Singapore, indicated more intense and frequent extreme rainfall events as a result of climate change.

Like the Netherlands, which had hard structures such as storm surge barriers to keep the sea out, Singapore has similarly built stormwater canals over the past 50 years to flush away storm runoff to mitigate flooding. Recently, there has been a a paradigm shift in thinking of how to bring water back into the city and to work with, instead of working against, water. This requires an evolution in the mindset of citizens about living with water. As opined by Tan Nguan Sen, Senior Consultant, Urban Liveability, PUB:

> *Children are brought up with the mindset that they should avoid getting wet in water. So it's really an uphill task to educate the younger generation to actually embrace water.*[10]

ROTTERDAM
Indicators

Land area (km²)
206.44

Population (million) – metropolitan area
0.64

Density (per km²)
3,060

% of land above/below sea level
85%
< 5 m below sea level

Annual rainfall (mm)
850

Flood-prone areas
31 HA
(unembanked areas)

Sea level rise
By 2100, up to
1 M

Drainage infrastructure
2,400 KM
of gravitational sewage system

250 KM
of pressurised pipes

1,000
pumping stations

4,000
waterways.

Critical infrastructure at risk
55%
of housing in flood-prone areas[11]

SINGAPORE
Indicators

Land area (km²)
719.1

Population (million) – metropolitan area
5.61

Density (per km²)
7,797

% of land above/below sea level
30%
< 5 m above sea level

Annual rainfall (mm)
2,166

Flood-prone areas
30.5 HA

Sea level rise
By 2100, up to
1 M

Drainage infrastructure
Singapore has an extensive network of about
8,000 KM
of drains, canals and rivers. Two-thirds of Singapore's land area is used as water catchment, collected through the drainage network before it is channelled to the country's 17 reservoirs.

Infrastructure at Risk
29 HA
of flood-prone areas (2018)

Key statistics for Rotterdam and Singapore

Distilling and sharing knowledge on climate-adaptive cities

Rotterdam and Singapore are part of the Connecting Delta Cities (CDC) network, which brings cities together to exchange knowledge in the field of climate change related spatial development, water management and adaptation to keep cities safe and liveable. In recent years, both the City of Rotterdam and the Centre for Liveable Cities (CLC) have established knowledge-sharing platforms to promote innovations in tackling water issues for both cities. These include lectures and workshops to discuss issues such as connecting water and opportunities (Rotterdam Mayor Ahmed Aboutaleb, 2012), coastal resilience and innovations against rising sea levels (Henk Ovink, Dutch Special Envoy for International Water Affairs and Daan Roosegarde, Founder of Studio Roosegarde and World Cities Summit Young Leader, 2016–17), and sustainability challenges and creating a circular economy from redeveloping old port sites (Rotterdam Deputy Mayor Adriaan Visser, 2017).

This collaborative research project between the City of Rotterdam's Office of Climate Adaptation and CLC further examines water management issues in the face of climate change. It will share lessons from both cities' multifunctional climate adaptation initiatives. Examples are recreational spaces that help flood mitigation and also use smart tools to engage the city and its residents. It will also share innovative financing models to guide shared investments in flood protection measures. It is hoped that this project will aid other cities in building the capabilities to address water issues arising from climate change.

Singapore and Rotterdam water experts exchange experiences on climate change adaptation.

2. LIVING WITH WATER: ROTTERDAM AND SINGAPORE

Rotterdam's vision

Rotterdam's approach: Too Much Water

Spatial planning and flood risk management issues in the Netherlands are guided by the National Adaptation Strategy, the Delta Plan on Spatial Adaptation under the national Delta programme (based on the Water Act) and the Spatial Planning Act.[12] Following devastating floods in 1953, the Dutch adopted flood management solutions, which prevented water from reaching the city. Subsequent flood events in 1993 and 1995, as well as global events such as the New Orleans floods were a turning point in water management, with the paradigm shifting to integration with spatial planning.[13] In 2006, the second Delta Committee recommended moving from "shutting the water out" to "living with water". This resulted in the national "Room for the River" project where river beds were widened to reduce flood risk and reconnect the city space to the rivers by improving the spatial quality in areas surrounding the rivers.[14]

The National Water Plan 2008 went a step further: it recognised that flood defences not only prevent floods but also reduce their impact. This gave rise to the Meerlaagseveiligheid flood risk management approach, which adopted a multilayer security approach where in addition to prevention measures, flood risk is reduced by adapting spatial planning and urban design of the city to include water management, and by introducing disaster management.[15] This is especially important in Rotterdam as much of the city, including the main port, lies in outer-dike areas. In areas outside of the primary dikes (un-embanked areas), where up to 40,000 people reside, asset/property owners do not enjoy flood protection and

bear the full economic consequences of floods.[16] At the low-lying quays of the Noordereiland area in Rotterdam, flooding from the river occurs almost annually.[17] Although the state has made it clear that citizens living and working in un-embanked areas are there at their own risk, it is not clear if the municipality will be held responsible for flood-related damage compensation.

Over the years, the Dutch coastal defence infrastructure has been built to withstand 1 in 10,000-year storm events, instilling a false sense of confidence in Rotterdam's resilience to climate change.[18] Many people are unaware if they live in an inner or outer dike area, and as much as 25% of the population is likely to ignore advice to leave the area in the event of an emergency.[19] The city is addressing this by raising awareness on flood risk through informational signage, floating infrastructure, and "building with nature" projects. There are even plans for an entire buoyant neighbourhood.

In Rotterdam, different aspects of water management are managed by various organisations and are financed on different levels. Primary flood protection from major rivers and against storm surges from the North Sea is handled by the national government and financed by the state's general funds (Delta tax). At the local level, planning documents identify and propose relevant studies that focus on flood risks, especially for development outside the dikes, such as Stadshavens.[20]

Flooding of un-embanked areas in Rotterdam by the River Maas in 2017.

In addition, the city works with the provincial authority and water boards to provide facilities to discharge runoff and efficiently process water in public areas. This is complicated by the city's combined sewers (70% of all sewers), which simultaneously collects surface runoff and sewage water in a shared system before transportation to the water authority's wastewater treatment plants. However, it is not feasible to reconstruct Rotterdam's sewerage system.[21]

To gain political buy-in for the adoption of climate adaptation measures in Rotterdam, urban planning was crucial in raising awareness. It was kick-started during the 2005 International Architecture Biennale Rotterdam (IABR) where "the Flood" was a key theme to frame water as a starting point for urban design in the city.[22] In 2007, Rotterdam revised its Water Plan to describe in detail the efforts needed to cope with increased water in and around the city. Solutions to collect and store up to 600,000 m^3 of water were proposed and included ideas such as green roofs and facades, water squares and infiltration zones as part of the urban scape to slow urban runoff and store rainwater. The Water Plan was further divided into 14 detailed sub-municipal plans, with each zone having a specific problem analysis and action plan to tackle bottlenecks in the water system.[23] As part of the action plan, urban planners were required to take into account in their planning processes the results of stress tests on infrastructure to consider flood risk and water retention.

Stadshavens is a former port situated in the city centre, which will be redeveloped in consideration of additional flood risks.

Organisation	Task	Financing
National/state water services under the Ministry of Infrastructure and Water Management (*Rijkswaterstaat*)	• Flood protection • Water quantity • Water quality (main system)	General resources, pollution levy, national waters
Province of South Holland	Care for groundwater and rainwater runoff	Regional tax
Water boards: Water Board of Schieland and Krimpenerwaard • Hollandse Delta Water Board • Water Board of Delfland	Flood protection (regional) • Water quantity • Water quality (protection of surface water from pollution) and wastewater treatment in embanked areas • Waste water treatment plants To be consulted during land use zone planning and has its own water legislation "keur", which describes water activities allowed near and in watercourses and near and on embankments.	Regional tax (amount of tax differs between the 22 regions in the country)
Water company: Evides (semi-public)	Drinking water supply	Price
Rotterdam municipality	• Collection of stormwater • Construction, management and maintenance of sewerage systems	Local tax (sewage levy, dependent on household size)

Organisations responsible for different aspects of water management in Rotterdam.[24]

At the city level, Rotterdam's efforts on climate adaptation are reflected in the Rotterdam Climate Proof (RCP) programme (2008), Rotterdam Adaptation Strategy (2013) and the Rotterdam Weatherwise. which started in 2018 and aims for the city to become fully climate-proof by 2025. In climate-proofing the city, Rotterdam Mayor Ahmed Aboutaleb explained it as follows:

> *We are aiming for Rotterdam being climate-proof in 2025. And this means that in 2025, we have implemented local measures to minimise the risks of climate change, but on the other hand, also profit off these changes. Both in this timeframe and the next decades, we have to act equally. Furthermore, we have to be able to cope with the uncertainties on the long-term by being both robust and flexible. The six themes we are working on are partly water-related, such as flood risk management and urban water system but adaptive building accessibility and city climate are also taken into account.*[25]

As a low-lying city situated in the deltas of the Rhine and Meuse rivers, about 85% of the city lies up to 7 m below sea level. As evacuation is almost impossible, climate adaptation is serious business for Rotterdam. Within the dikes, the inner-dike city of Rotterdam is mostly well below sea level, with the lowest point 6.67 m below mean sea level in the Alexanderpolder district. Climate adaptation measures within these areas adopt the *Meerlaagseveiligheid* approach by redesigning the city to create more space for water storage.

Urgency is needed to implement more of such climate-adaptive solutions in the city given that much of Rotterdam lies mainly on clay, making it difficult for rainwater to infiltrate the ground which, in turn, leads to higher levels of urban runoff.[26] The funding of these solutions is largely derived from sewage levies. Nevertheless, with more drought and heat waves expected in the future, the municipality can no longer fund these projects using only sewage levies. Hence, Rotterdam also shares the responsibility for urban flooding and climate-proofing the city's infrastructure with private actors by raising climate change awareness and engaging stakeholders early.

Approximately 85% of Rotterdam is less than 5 m above mean sea level, putting neighbourhoods under flood risk.

WATER MANAGEMENT POLICIES IN ROTTERDAM

1953 – Flood event

Flood management – "Shutting out Water"

1954 – Start of the national Deltaplan – a national programme to strengthen coastal flood defences and reduce flood risk

1997 – Maeslantkering finished (Deltaplan completed)

2001 – Rotterdam's Water Plan 1 – the city's first action plan to address flooding

Manage flood risk + water management

2005 – Rotterdam Water City 2035 vision & the Flood IABR

Manage flood risk + water management + spatial planning

2007 – Rotterdam's Water Plan 2 – a municipal plan with water management strategies and flood monitoring (both reduction of flood risk and water retention measures)

2008 – Rotterdam Climate Proof programme – knowledge, actions and marketing communications plan for Rotterdam to be climate-proof by 2025

Manage flood risk + water management + spatial planning + climate change

2010 – Connecting Delta Cities – a Rotterdam-founded network of cities active in climate adaptation to exchange knowledge and share best practices

2011 – Recalibration of Rotterdam's Water Plan 2

2013 – Rotterdam Adaptation Strategy – an updated and comprehensive implementation strategies to become climate-proof by 2025

2015 – Rotterdam Programme on Sustainability and Climate Change (2015–18) – the first official document that combines mitigation and adaptation initiatives to meet 2025 goals

Manage flood risk + water management + spatial planning + climate change + resilience

2015 – Launch of Rotterdam's Resilience strategy – connecting the effects of climate change to other challenge in order to have an integrated approach

2016 – Deltascenario's Rijmond-Drechtsteden – one of nine sub-programmes within the Delta programme Rotterdam Resilient City

Future

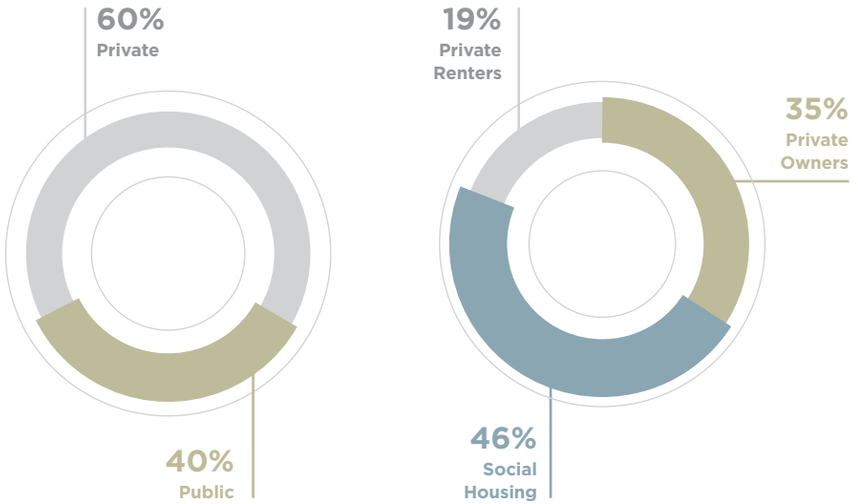
2019 – Rotterdam Weatherwise

2020 – World Adaptation Week Rotterdam

Learning to live with more water

Recognising that water will be a recurrent challenge, Rotterdam developed the Rotterdam Weatherwise plan. Beyond water safety infrastructure, the plan aims to create a bottom-up movement to involve both public and private actors in implementing climate change adaptation measures. As 40% of the city is publicly and 60% is privately owned, public space operators can have a significant impact if they adopt adaptation measures. In working with the different housing corporations and private home owners, the municipality faced challenges in climate-proofing homes as 46% of the population live in social housing, with 35% private owners (comprising a mixture of income groups) and 19% private renters, thus different strategies were needed for each group.

Rotterdam Weatherwise mainstreams climate change awareness by integrating the reduction of climate change vulnerability into the city's broader development aims.[27] The plan focuses on water safety, heat, drought, rain, groundwater and soil subsidence. There is already a clear vision and strategy regarding rain, heat, drought, and water safety in the Rotterdam Adaptation Strategy, the Resilience Strategy, the Sewerage Plan, strategic asset management, Rijmond-



Distribution of private and public property in Rotterdam (left), and ownership of private property in Rotterdam (right).

Drechtsteden Delta programme and the Water Plan. These plans are still relevant and are the starting point of the Rotterdam Weatherwise. The goal is to create a coordinated strategy for all the themes and link them to climate-proof constructions. These measures can be taken by the citizens of Rotterdam and housing corporations with the help of the municipality, which will subsidise these measures. For citizens and housing corporations to receive funding or subsidies for climate-proofing measures, the strategy of the Delta Plan Rotterdam has to be approved by the local government.

Rotterdam Weatherwise has three major group of measures for climate-proofing. The first relates to measures for public spaces, public real estate and schools. The second relates to measures taken by the city government to raise awareness on the risks of climate change. As each neighbourhood has its own characteristics and risks, in-depth dialogue is conducted at the neighbourhood level. Furthermore, city authorities hold dialogues with citizens, the private sector and social housing corporations. The last group of measures relates to the private sector. The office will launch a subsidy programme in January 2020 to finance climate-adaptive measures for homeowners and social housing corporations.

Rotterdam incentivises climate-proofing measures by regulating new buildings and subsidising the retrofitting of existing ones. Housing corporations and citizens may apply for subsidies. The goal is to encourage residents, companies and organisations to adopt innovative climate adaptation measures, which must contribute to:

- Increasing water-holding capacity;
- Reducing the amount of rainwater on the sewer system;
- Countering the heating of the city;
- Reducing the effects of drought; and
- Awareness among the broader public about climate change and climate adaptation.

Opening of a climate-proof school yard in 2018.

A climate-resilient Singapore

Too little water and extreme water: Singapore's sustainability journey

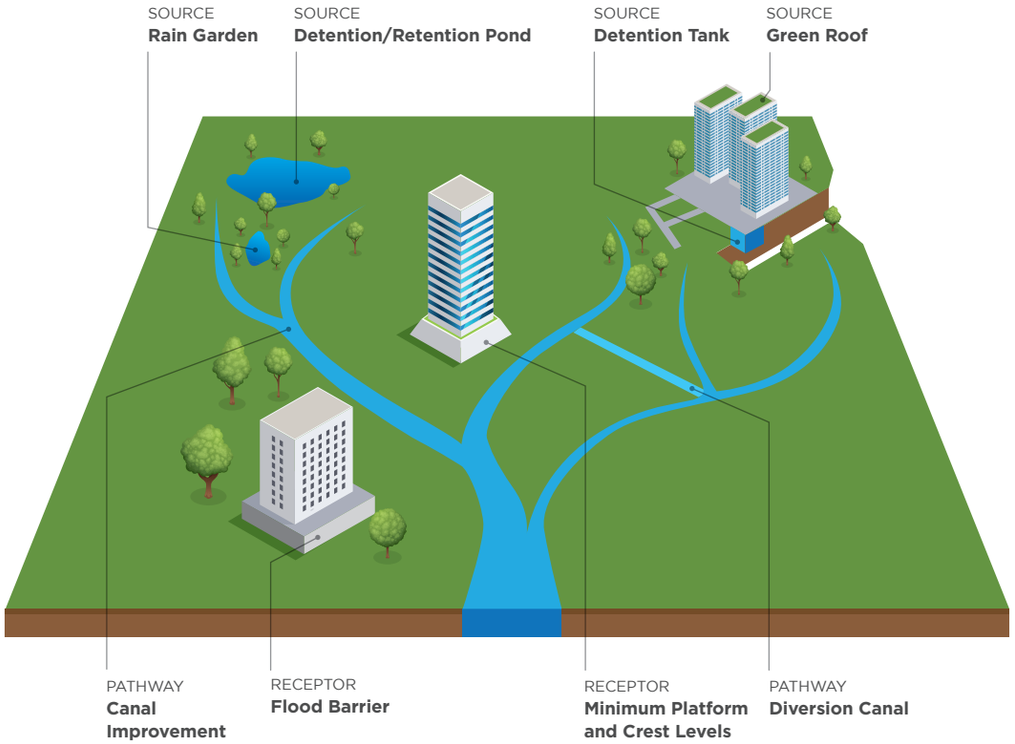
Since independence, Singapore has sought to achieve a balance between economic development and a sustainable living environment. Singapore's tropical climate means that the country experiences distinct wet seasons characterised by heavy rainfall and periods of dry weather. However, Singapore's problem is not lack of rainfall but lack of space to capture and adequately store water. The management of Singapore's complicated water challenges thus required an integrated urban systems approach.

Water infrastructure in Singapore in the early days of its independence was developed out of necessity and initially served to increase water supply and manage floods in isolation. Under the 1972 Water Master Plan, a water catchment policy was developed, which oversaw the development of catchment areas and reservoirs to collect rainwater to boost local water supply.[28] Singapore's first reservoirs, including MacRitchie Reservoir and Lower Seletar Reservoir, were privately developed during the colonial period to increase water supply.[29] However, many of these water catchments could not cope with the increasing demand for water that came with rapid population growth.

Singapore also faced the threat of inland flooding during the post-independence years, when the country underwent rapid urbanisation. To combat flooding, authorities implemented an islandwide drainage network, which competed with other infrastructural demands in already land-scarce Singapore. Hence, there was a need for an integrated approach to planning at an urban systems level to optimise land for different infrastructural needs. The first drainage masterplan was thus developed in close consultation with development agencies like the Urban Redevelopment Authority (URA), Housing and Development Board (HDB) and Jurong Town Corporation (JTC).

At a broader level, this drainage plan was part of a plan to strengthen Singapore's water security by increasing water supply (the construction of reservoirs), improving sanitation (through the provision of a sewage network) and finally, flood prevention (with the development of a comprehensive drainage masterplan).[30] This resulted in the development of an extensive drainage network consisting of approximately 8,000 km of drains, canals and rivers. These water networks have been integrated gradually to ensure water sustainability for Singapore, working together to overcome water shortage issues, while mitigating inland flooding.

Singapore is now preparing for more intense and frequent extreme storms. To cope with the intense rainfall, PUB, Singapore's national water agency has adopted a "source-pathway-receptor" approach, which uses catchment-wide solutions to achieve higher levels of flood protection. This holistic approach allows the system to be flexible and adaptable, addressing not just the drains and canals through which stormwater travels (pathway), but also in areas where stormwater runoff is generated (source) and areas where floods may occur (receptor). Singapore has continued to adapt its approach to managing scarce water resources over time, while striking a balance with urban development and meeting other national priorities. By integrating the management of water infrastructure, it has managed to systemically manage inland flooding while retaining sufficient space to capture rainwater to augment drinking supply.



Examples of Singapore's "source-pathway-receptor" approach for flood protection.

EVOLUTION OF WATER MANAGEMENT POLICIES IN SINGAPORE

Increase water supply

1963
The Public Utilities Board (PUB) was set up as a statutory board to coordinate the supply of electricity, piped gas and water.

Pre-1965
Development of private and colonial government-funded reservoirs.

1965–69
Development of protected water catchments (MacRitchie Reservoir, Peirce Reservoir and Seletar Reservoir).

1972
Publication of the Water Master Plan, which outlined the development of catchment areas and reservoirs to collect rainwater to boost local water supply. Non-conventional sources such as water reclamation and desalination were also recommended but shelved due to feasibility issues.

1975–81
First unprotected catchment created by damming the Kranji, Pandan, Murai, Poyan, Sarimbun and Tengah Rivers in the north-western region of Singapore.

2004
Start of the reservoir integration scheme to boost reservoir holding capacity by transferring water from one reservoir to another.

Manage flood risk

1966
Start of the Bukit Timah Flood Alleviation Scheme.

Mid-1970s
Adoption of the Drainage Masterplan to guide the provision of drainage systems and set aside drainage reserves for future requirements.

Manage flood risk and increase water supply: Multifunctional urban projects and living with water

2001
The Public Utilities Board was reconstituted as PUB, Singapore's National Water Agency, overseeing the entire water loop including sewerage and drainage functions.

2002
NEWater, recycled water, was publically unveiled.

2005
Desalination introduced with the opening of Singapore's first desalination plant.

2006
Introduction of the Active, Beautiful, Clean Waters (ABC Waters) Programme.

2008
Completion of the Marina Barrage, which provides flood prevention, increasing water supply and recreational functions.

2016
Release of the Climate Action Plan.

2019
Designated Year Towards Zero Waste and publication of the inaugural Zero Waste Masterplan.

FUTURE

Ongoing
Adapting to sea level rise: raising minimum reclamation levels, mangrove restoration projects and geobags to combat rising sea levels and coastal erosion, installing flood barriers at underground low-lying Mass Rapid Transit (MRT) stations, building future development including Changi Airport Terminal 5 and the new Tuas Megaport to higher standards.

Ongoing
R&D to reduce the energy requirements to recycle or desalinate water through biomimicry, including through the development of biomimetic membranes from aquaporins, which are transmembrane proteins found in living organisms.

Learning to live with too little or extreme water events

Although Singapore has developed an integrated water management system, increasing urbanisation and climate change require a diverse range of interventions to help manage flood risks more effectively.

Increasing urbanisation and changing rainfall patterns

Over the last few decades, Singapore has undergone rapid urbanisation, and its population has grown from 1.6 million people in 1960 to 5.64 million in 2018.[31] With the development of high-density satellite towns, residential and commercial developments, there has been an increase in impervious surfaces, resulting in higher peak runoff during storm events.[32] Adding to this challenge is the effects of climate change on weather in Singapore, where more intense storms are expected to occur. The city-state is currently experiencing some of these effects, with unprecedented weather patterns in recent years.

According to the Second National Climate Change Study, there has been a general uptrend in annual average rainfall, from 2,192 mm in 1980 to 2,727 mm in 2014.[33] During intense storms, peak runoff from the urbanised catchment may exceed the capacity of public drains, resulting in flash floods. In January 2018, flash floods occurred in nine locations in eastern Singapore. The heaviest rainfall recorded then was 118.8 mm, almost half the monthly rainfall in January.[34] In June 2018, flash floods also hit several areas in the central part of the island with one particular area receiving about 85 mm of rainfall over a two-hour period, which was more than half the average rainfall for the entire month of June.[35]

Current plans for flood management include investing S$400 million over the next two years to improve the drainage network and make monsoon drains and canals bigger, while fortifying older structures.[36] However, widening drains to increase drainage capacity comes with challenges in land-scarce Singapore, as former Minister Mentor Lee Kuan Yew said:

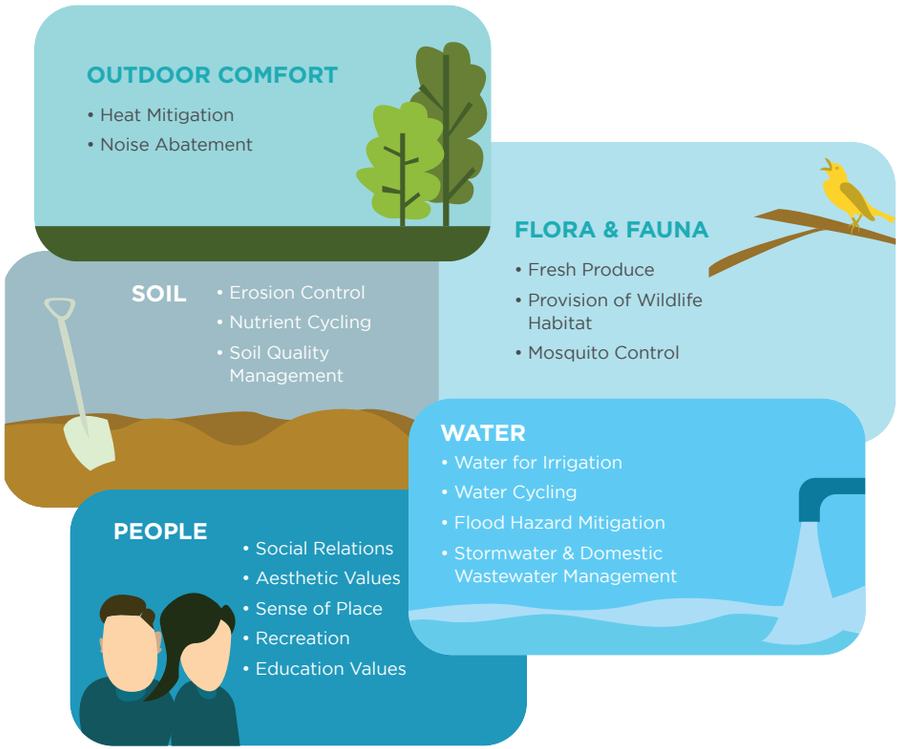
> *There is a limited amount of space that you can dig underground, limited amount of space that you can have runoffs for canals.*[37]

Changing rainfall patterns is expected to be a long-term challenge.[38] As such, there is a need to prepare ahead by looking beyond expanding drainage infrastructure and plan for more space-efficient infrastructure to cope with increasingly intense storms.

Paradigm shift to reconnect the city with water

In recent years, many cities have adopted flood management practices that have shifted away from traditional engineering approaches on keeping the water out and investing purely on drainage systems, to "building with nature", which advocates working with natural systems to meet the need for infrastructure while creating opportunities for nature.[39] This approach was used in the Dutch "Room for the River" programme, which started in 2007 along the River Rhine, where dikes were relocated to increase the width of the floodplain, returning farmland back to natural development.[40] Similarly in Singapore, PUB's Active, Beautiful, Clean Waters (ABC Waters) programme was launched in 2006 to transform waterways and waterbodies into urban assets by integrating drainage infrastructure within the built environment and bringing people closer to water.[41]

Vertical greenery is increasingly used to manage and delay stormwater runoff and address urban heat island effect in Singapore.

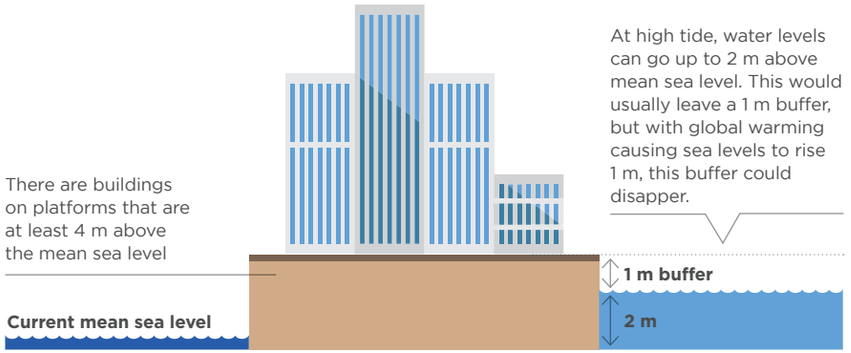


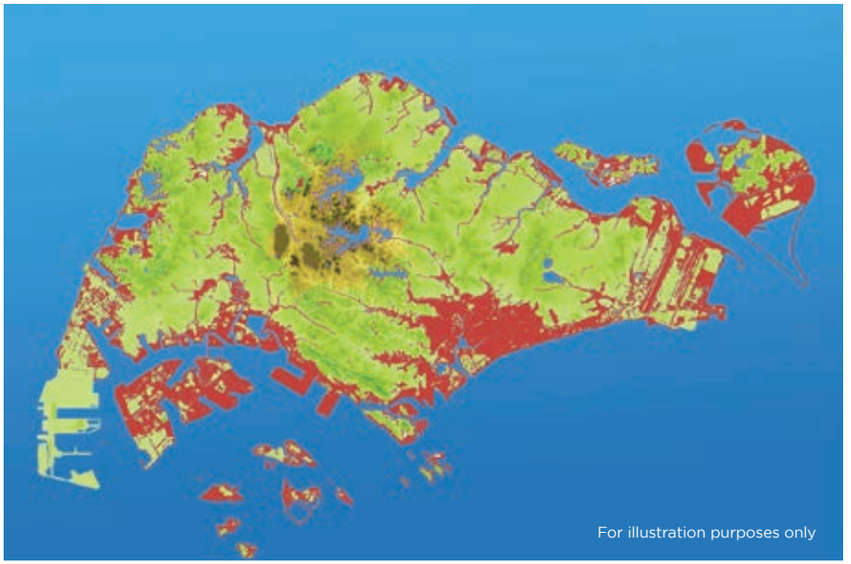
The HDB's Biophilic Town Framework, elements of which are illustrated here, provides a guide to create nature centric neighbourhoods so that residents can connect with water and greenery.

Yet more can be done to reconnect the city to water, especially in dense cities, where green and open spaces play a critical role in accommodating stormwater runoff to reduce the flooding of critical infrastructure such as buildings and roads. In designing for more space in the city to accommodate stormwater runoff, it is essential to create spaces that can serve as both a recreation area and an area for flooding during a storm event. The design of multifunctional flood spaces in Rotterdam is the focus of the city's water management strategy. Underground tanks may function as effective water storage measures but they require a higher capital outlay and are perceived as less effective. Therefore, the city has adopted a strategy that locates new water storage systems on the surface to make them explicit and allow it to contribute to the environmental quality of urban space, while also strengthening neighbourhood identities and serving as recreational spaces.

In Singapore, the idea of multifunctional urban spaces for flood management is advocated in the HDB Biophilic Town Framework, which serves to guide the enhancement of existing natural assets and the development of residential landscapes to enhance liveability. The Framework's guidelines on flood and hazard mitigation suggests designing multifunctional green and open spaces (e.g. sports fields, outdoor basketball courts, paved plazas) to function as emergency flood detention basins during extreme storm events.[42] The incorporation of building with nature and nature-based features in multifunctional spaces were also identified for further exploration in the 2018 ABC Waters design guidelines, which has transformed how Singapore manages surface water runoff. This is especially evident at public plazas, which are commonplace in Singapore's urban landscape such as in commercial and retail spaces. In promoting creative ways to incorporate multifunctional spaces for flood management, Rotterdam and Singapore are also creating more vibrant cities for their residents.

Public plazas are being built with flooding and water sensitivity in mind.





Illustrative map of Singapore's low lying areas potentially prone to greater flood risk with the rise of mean sea level.

Rising sea levels

As a low-lying island, Singapore faces existential challenges from rising sea levels. Much of the city state is only 15 m above mean sea level, with approximately 30% of the island less than 5 m above mean sea level. Under the Second National Climate Change Study, the Centre for Climate Research Singapore projected that sea levels around Singapore could rise by up to 1 m by 2100. Current coastal protection measures adopted by Singapore include raising the minimum land reclamation and platform levels from 3 m above the mean sea level to 4 m. Critical infrastructure such as the new Tuas Port and Changi Airport Terminal 5 will be built even higher at 5 m and 5.5 m above mean sea levels respectively.

Beyond a pumping station, Marina Barrage was built to double as a recreational space; the rooftop is now a popular kite flying spot in downtown Singapore.

Marina Barrage, completed in 2008, created Singapore's 15th reservoir with a catchment of 10,000 ha, and is part of the flood control measures for low lying areas in the Central Business District.

An artist impression of Singapore's pilot polder development at Pulau Tekong.

Currently, sea walls and stone embankments span 70% to 80% of Singapore's coastline.[43] The existing Marina Barrage protects Singapore's Central Business District from flooding. A second pump house at Marina Barrage is also being planned to cope with potential extreme flooding events.

In August 2019, the Singapore Government shared its long-term plan to protect its coasts, which may cost up to S$100 billion in the next 100 years. This involves studying the low-lying areas along Singapore's coastline in greater detail to develop appropriate flood protection strategies, including the possibility of integrating coastal protection measures such as polders and dykes in upcoming development plans.

Infrastructure is not the only focus. Singapore will also spend S$900 million on R&D for urban solutions and sustainability, and launched a Climate Action Package in 2018 to support ASEAN countries in areas such as climate science, flood management and disaster risk reduction.

Singapore also hosts the ASEAN Specialised Meteorological Centre (ASMC) and is investing S$5 million in a five-year capability development programme to strengthen the region's efforts in climate projections and adaptation planning.[44]

Vertical greenery is being encouraged in all new buildings, including public housing.

3. FROM VISION TO ACTION: CASE STUDIES FROM ROTTERDAM AND SINGAPORE

The earlier section outlined how both cities have overcome water challenges in their own ways and are looking to solve new challenges brought about by climate change. As the effects of climate change take place over several decades and its risks are uncertain, adaptation to climate change requires a multi-pronged approach. In worst-case climate scenarios, decision makers may focus on robust strategies when the consequence of not taking precautionary actions is high, like the Netherland's Delta Works plan to combat rising seas and storm surges and Singapore's Four National Taps strategy that makes securing water supply a national priority. However, in situations where doing nothing is risky and uncertainty about the future makes taking decisive action difficult, strategies should not be based on a single or limited number of climate scenarios. Instead, designs should be integrated and flexible to adapt to changing circumstances.

This section focuses on case studies from Rotterdam and Singapore and offers unique insights into each city's approach to deal with increased urban water runoff and rising sea levels due to climate change. The case studies go beyond mere outcomes observed and examine underlying challenges and success factors in the process of planning and implementing each programme or project. Through these case studies, the research hopes to elicit key learnings on how each city is redesigning urban space to integrate water. The case studies are organised into four themes covering various key aspects of water management initiatives and the measures taken to address climate change challenges: Small-scale adaptive measures, flexible infrastructure, climate-proofing neighbourhoods, and outreach programmes.

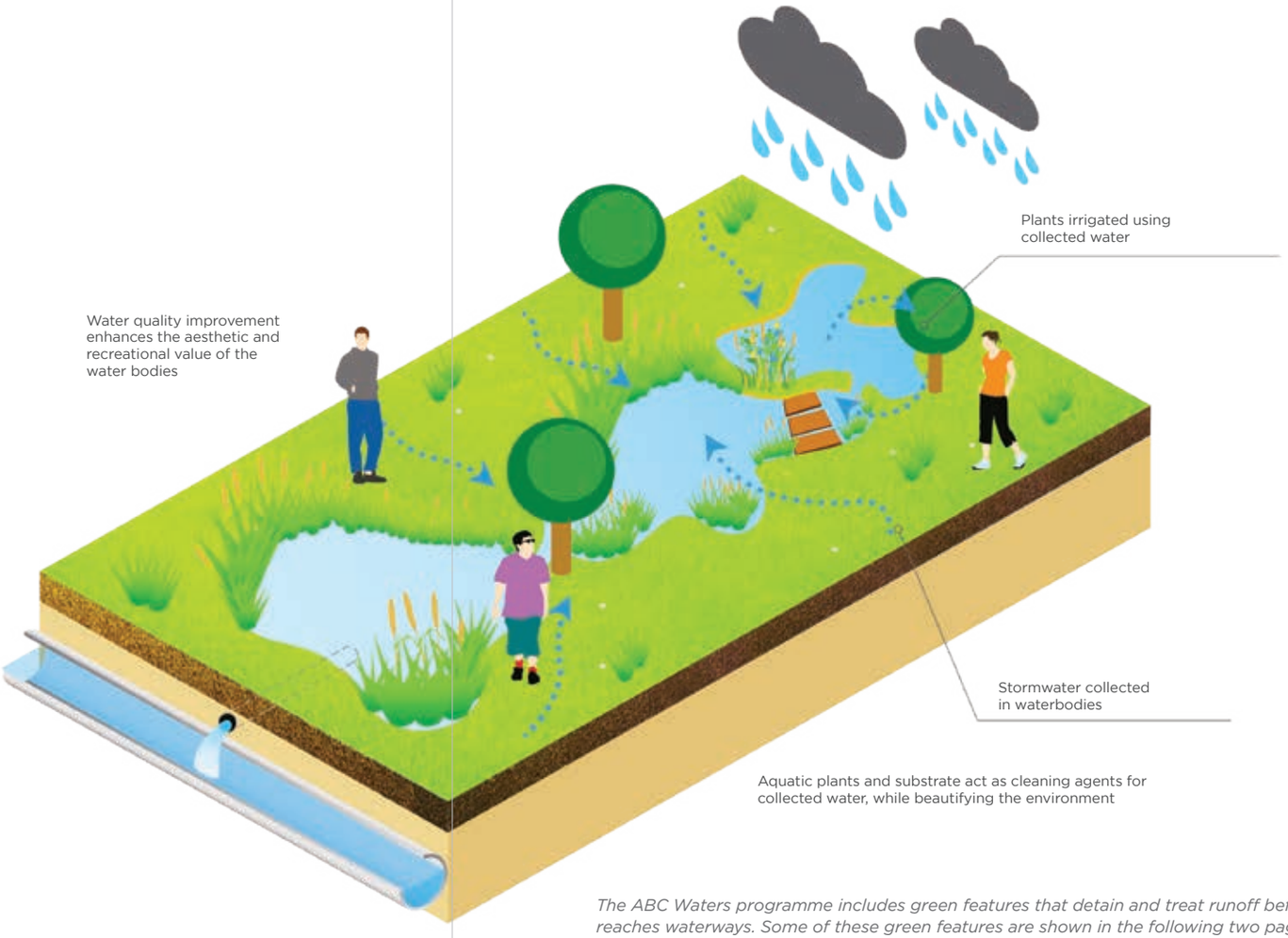
Small-scale adaptive measures

Flood management strategies are designed to reduce the probability and risk of flood events and usually require major urban interventions that are almost entirely publicly funded. Where public resources and funding are limited, major infrastructure solutions may not be sustainable in the long-term due to the high cost of adapting infrastructure to the impacts of climate change.

To complement ongoing major infrastructure works, both Rotterdam and Singapore aim to introduce localised solutions to slow the flow of peak stormwater runoff. In the case of the Dutch, small-scale adaptive measures are part of the multilayer (Meerlaagseveiligheid) security approach to reducing flood risks, balancing preventive measures, adaptive measures and disaster management measures.[45]

Similarly, the ABC Waters programme is a long-term initiative to transform Singapore's drains, canals and reservoirs into beautiful streams, rivers and lakes that are integrated with the surrounding landscape. As two-thirds of Singapore's land is used for water catchment, the programme aims to ensure good quality rainwater is conveyed to reservoirs. ABC Waters aims to foster stewardship of the waterways and bring Singaporeans closer to water so they cherish and value this precious resource. As of 2019, 43 ABC Waters projects have been completed.

Beyond aesthetic benefits, the programme involves incorporating environmentally sustainable green features within the urban environment to detain and treat runoff before it reaches the waterways.[46] PUB works with agencies and developers to integrate such features into new projects. Plants and soil are used to improve water quality of runoff near to the source before the cleansed runoff is discharged into public drains. When implemented catchment-wide, they improve the water quality of reservoirs and waterways. These features also enhance the aesthetics and biodiversity of the surrounding area and help to slow runoff into the waterways. Examples of ABC Waters design features include bio-retention basins (rain gardens), bio-retention swales, vegetated swales, cleansing biotopes and constructed wetlands. When adopted holistically as part of the stormwater management system, they introduce additional flexibility to the system to allow it to cope with increasing urbanisation and uncertainty arising from climate change.



The ABC Waters programme includes green features that detain and treat runoff before it reaches waterways. Some of these green features are shown in the following two pages.

Sedimentation basin at Sungai Ulu Pandan.

Constructed wetlands at Lorong Halus.

Vegetated swale and rain garden at Kallang River, Potong Pasir.

Cleansing biotope at Bishan-Ang Mo Kio Park.

Green Roofs and Urban Water Buffers (Rotterdam)

Rotterdam's urbanscape is characterised by flat rooftops, totalling 14.5 million m^2. These rooftops offer opportunities for water storage, harnessing of solar and wind energy and serving as public spaces. In 2008, the five-year Green Roofs programme was conceptualised with the aim to create 160,000 km^2 of green rooftops using succulents and mosses to help mitigate the effects of increasingly heavy downpours that overload the city's sewers.[47] To further develop rooftop uses, the municipality received a substantial European Union subsidy in 2017 to implement the LIFE@Urban Roofs project, which encourages developers and building owners to invest in climate adaptation measures.[48] As part of the project, a design contest for multifunctional roofs and a social cost-benefit analysis were carried out at three demonstration sites in the city, including Robert Fruinstraat, where Water Sensitive Rotterdam (WSR), with the help of the residents, companies and institutions, initiated a new climate-adaptive design for the street in early 2016.[49]

While Rotterdam actively redesigns its city space to create more room for water, there are limitations to the amount of space created for water retention and infiltration in urban areas due to competing above-ground uses of space and limitations to expand drainage infrastructure due to the combined sewer system. Apart from Green Roofs, the city also initiated the Urban Water Buffers programme in 2018, which aims to retain and reuse rainwater in urban areas for a longer period, without obstructing other functions at ground level. The buffers use deeper aquifers to infiltrate, store and extract rainwater through wells, as part of retaining rainwater in the city's subsoil.[50]

A green roof that retains water next to the Rotterdam central railway station.

Robert Fruinstraat: Mainstreaming climate adaptation in the sewerage renewal programme

Robert Fruinstraat is a typical street in the neighbourhood of Middelland, located between Centrum and Delfshaven. Its sewage system, gas infrastructure and electricity grid are ageing and ripe for renewal. To redesign the street to be climate-proof, WSR gathered private homeowners, housing association Woonstad, representatives of the local church and the women's association, water company Evides, private real estate developer Rotterdamse Vastgoed Maatschappij and the water board to decide on key sustainability elements such as the incorporation of green roofs with an innovative urban water buffer located next to the Spartaplein football stadium.[51]

Several workshops were held to involve the community in the design for the street. Rather than a standard participation procedure in which local stakeholders contribute once or twice on municipal proposals, an intensive participatory process was carried out during the design stage of Robert Fruinstraat. Urban planning firm Bosch Slabbers initiated a process for knowledge development on sustainable, attractive and adaptive redesign, and Robert Fruinstraat was used as a testbed for the redesign through the road medium of StraaDkrant. Besides redesigning the street and integrating climate adaptation measures, Atelier Groenblauw conceptualised a design for flooding nuisance within the adjacent building block in consultation with the affected private homeowners.[52]

Artist's impression of Robert Fruinstraat, highlighting potential spaces for water-sensitive design and urban greenery.

In June 2017, the preliminary design for Robert Fruinstraat was presented to the residents.[53] Although mainstreaming climate adaptation at the street level began in a top-down manner by the municipality to communicate the urgency of taking action and incorporate the integration of sewerage renewal plans, over time, community involvement translated into a recognition of the opportunity to improve public space and their homes.

Benefits of Green Roofs and Urban Water Buffers

Rotterdam was one of the first Dutch cities to encourage the installation of green roofs by providing an attractive subsidy for homeowners and led the way by introducing them at a number of municipal buildings.[54] While it is a small-scale measure, these rooftops buffer rainwater instead of allowing water to drain straight to the streets and sewers. To further encourage private owners to undertake sustainable rooftop development, a social cost-benefit analysis was carried out under the LIFE@Urban Roofs project to lay out the benefits and costs involved. Initial findings of the study at Peperklip (a large, low-income housing project) stated benefits such as a 10% increase in property value due to an increase

Rotterdam provided an attractive subsidy which led to the conversion of many more rooftops to green roofs (left and above).

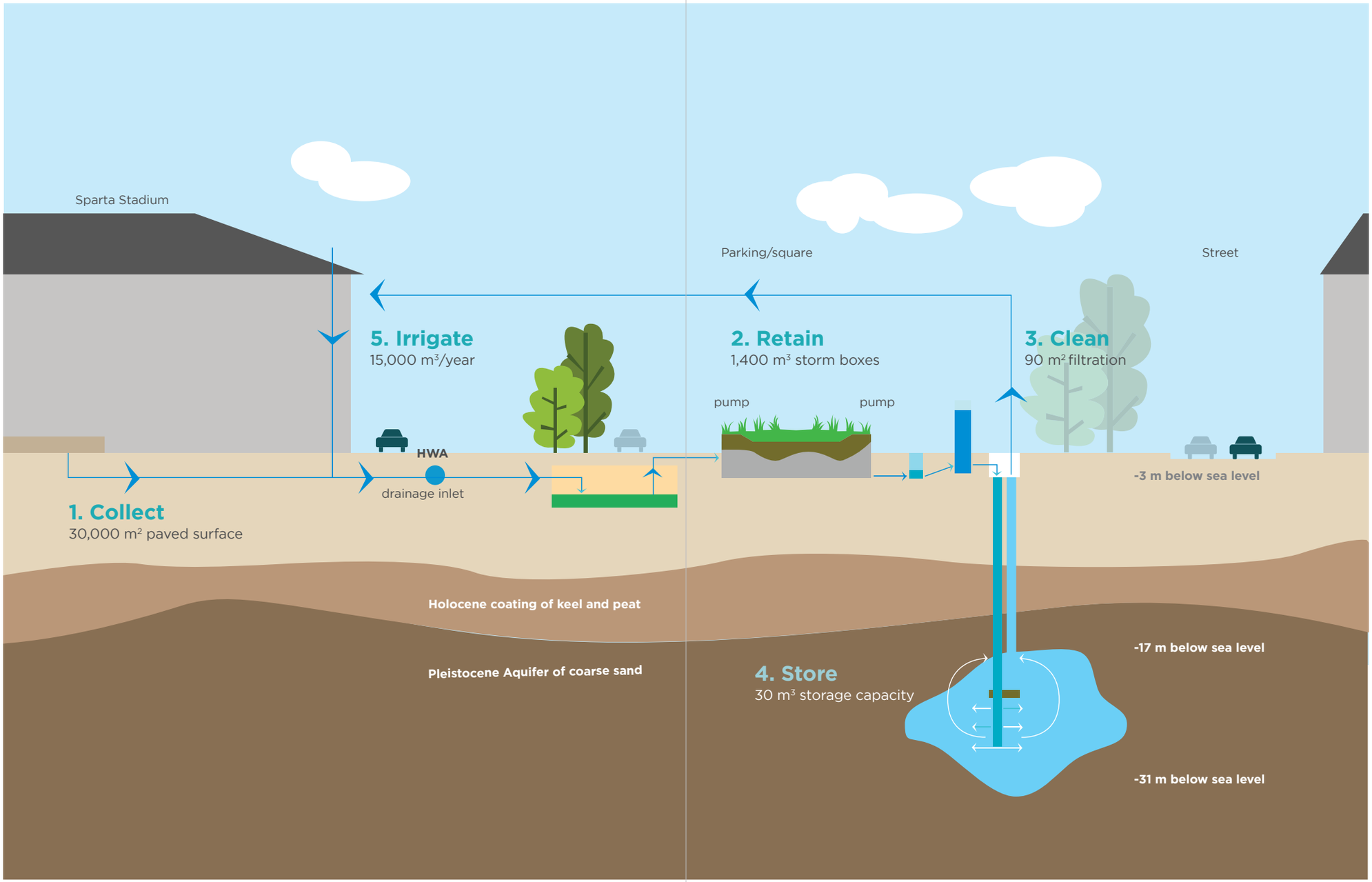
in aesthetic value, with higher values achieved when there is view of green/blue roofs at the ground level. Other benefits included a 3 dB noise reduction and cooling effects in the immediate surroundings.[55]

The green roofs enhanced workers' productivity and comfort during a 40 second micro-break. The roofs also provided cost savings of 500 euros/m^3 (S$774/$m^3$) because of water avoided at ground level/underground.[56] In other areas of Rotterdam, such as Oud Mathenesse, 25% of green roofs were designed with a retention capacity of 25 mm, reducing the annual overflow volume by 19.5%.[57] In the case of the Alexandrium shopping centre, home to Europe's largest green rooftop at 21,020 m^2, the city council funded 25% of the construction costs, while water authorities contributed another 5%. With such a large surface area, the green roof delays as much as 770,000 L of rainwater into the sewers.[58]

Nevertheless, green roofs are limited in their rainwater retention capacity due to other design factors such as the slope of the roof, consistency of the layers, and thickness and type of substrate. To holistically manage the water cycle, Rotterdam's Urban

Water Buffers programme is the latest in the slew of small-scale climate adaptation measures the city is incorporating into urban areas. The buffers project involves three municipalities (Rotterdam, The Hague and Rheden) and is jointly carried out with stakeholders from the water boards and financed by the Supplement for Top Consortia for Knowledge and Innovation (TKIs) from the Ministry of Economic Affairs and Climate Policy.[59] To better translate Dutch science policy to societal and economic impacts, TKIs were introduced as early as 2011. They are provided with an initial budget of 500 million euros (S$774 million) by the national government, with an estimated 800 million euros (S$1.238 billion) in total to be contributed by the public and private sectors by 2020, with at least 40% from industry.[60] Comprising a consortium of industry, knowledge institutions and the authorities, TKIs engage in research initiatives across nine knowledge-intensive and export-oriented sectors, including water, energy, and creative industries among others.

From late 2017 to mid-2018, work on urban water buffer pilot projects in Rotterdam and Rheden were conducted, and their implementation will be monitored by TKIs for at least one year. The first phase of TKIs' Urban Water Buffers programme included pilot projects at four sites: Rotterdam-Spangen, Rotterdam-hNI, Rheden and The Hague. Preliminary results show that, particularly in Rotterdam and Rheden, water buffers can have a concrete, short-term contribution to the discharge of approximately 1,400 m^3 of surplus stormwater and thus to flood prevention. At Spangen, the water retention capacity of the buffers was 50 mm, which was combined with a bio-filtration system prototyped at the Green Village, an innovation test site in Delft.[61] The Spangen water buffer serves to collect and purify rainwater that falls on the roof and parking areas of the neighbouring Spartaplein football stadium before being reused for watering the club's artificial turf field, which has a higher water consumption than natural grass fields.[62]



TKIs' Spangen water buffer collects and purifies rainwater, which then waters the Spartaplein football stadium's fields.

Active, Beautiful, Clean Waters (Singapore)

In 2006, the Active, Beautiful, Clean Waters (ABC Waters) programme was launched to transform Singapore's waterways and waterbodies into beautiful urban assets, integrating these drainage infrastructures with the built environment, while bringing people closer to water. The strength of this programme lies in its unique approach to get people involved in ensuring the sustainability of scarce water resources. Community engagement has been an important aspect of this programme, which has opened up "blue" spaces for recreation, contributing to Singapore's liveability.

ABC Waters features in Holland Plain, Singapore.

Key components of the Active, Beautiful, Clean Waters (ABC Waters) programme.[63]

Apart from introducing water to the city and people, ABC Waters is holistically linked to Singapore's stormwater management strategy. ABC Waters promotes the use of natural systems to temporarily absorb stormwater so that peak runoff to waterways is reduced, lowering flood risk during heavy storms when incorporated on a catchment-wide level. Such systems can be designed as part of landscaped spaces for people, optimising community spaces by doubling up as water infrastructure. These ideas are encapsulated in the programme's acronym, "ABC". ABC Waters also illustrates the potential of small-scale adaptive design features for site-specific conditions. The programme's key value lies in its ability to integrate different uses and maximise land space in dense urban areas.

Water as an environmental asset

The implementation of ABC Waters creates a paradigm shift where water is seen as a crucial component of the urban fabric. Thus, waterways and waterbodies are increasingly managed as environmental assets and are used to create new social, cultural and economic value in urban spaces. In the past, Singapore's approach to managing water resources was to keep people away for safety and security reasons. Public education was introduced in the early 2000s as a way to keep waterways and waterbodies clean. In 2004, reservoirs were opened for water-based recreational activities. Railings and hard barriers were replaced with natural barriers like vegetation and boulders at some sites to transform them into inviting spaces, while creepers were used to soften the hard look of concrete canals. These measures sought to bring people closer to water while educating the public on the need to keep waterways and waterbodies clean and fostering a sense of water consciousness.[64]

Despite government support, there was skepticism about the value of the ABC Waters programme. There was a need to seek buy-in from Members of Parliament for the programme as they would play crucial roles in getting grassroots leaders involved in adopting completed ABC Waters sites, and to encourage the community to enjoy the ABC Waters sites and related facilities

Waterway Ridges in Punggol was designed with bioswales with natural barriers such as vegetation and boulders, following the guidelines of the ABC Waters Programme.

in a responsible manner. To ensure the implementation of the programme, PUB set up an inter-agency working committee and held monthly meetings with various stakeholders to resolve issues. Even within PUB, work went into ensuring that engineers were convinced of the benefits of integrating waterways with land use and that the implementation of ABC Waters design features would not detract flood management but instead, aid in managing stormwater runoff.[65]

Apart from the initial cost of construction, the long-term cost of maintaining ABC Waters design features had to be addressed. Bio-retention swales need to be checked to ensure that filtration mediums are not clogged.[66] Over-riding cost consideration, there was an enlightened understanding that the creation of new value for previously underused waterways and waterbodies under the ABC Waters programme has immense potential to improve the environment.[67]

ABC Waters design guidelines have informed more than a hundred large and small projects across Singapore, providing not only smart water detention sites, but improving the greenscape as well.

From concrete drain to meandering river: Kallang River

Bishan-Ang Mo Kio Park is a good showcase of the ABC Waters programme. Previously, the park was a green buffer adjacent to the Kallang River—a 2.7-km long concrete canal for drainage and flood control during heavy downpours. In the 2000s, both the park and canal were due for refurbishment, and the decision was jointly made by the National Parks Board (NParks) and PUB to convert the concrete canal into a meandering, naturalised waterway, resulting in the creation of a new recreation space.

As the location is surrounded by HDB estates, it was a natural place for residents to develop a relationship with water and understand the importance of conserving water and keeping waterbodies clean. PUB therefore engaged residents in the design phase to ensure they were educated on using the naturalised canal in a responsible and safe manner, as there would be no railing to separate the new waterway and park. Through the process, the public was also reminded that everyone had a part to play in keeping the waterways clean and protecting water resources. Additionally, PUB encouraged schools to develop educational learning trails and experiential programmes for students to learn how to appreciate water and keep the river clean.

As a result of these measures, when Bishan-Ang Mo Kio Park was reopened in 2012, it quickly became a much-loved green space, attracting not only people, but flora and fauna as well. Otters, in particular, have established homes in the waterways and are well-loved by the community.

Before, Bishan and Ang Mo Kio neighbourhoods were divided by this concrete canal. The waterway was re-naturalised and integrated with the adjacent park, using ABC Waters design features.

The Bishan-Ang Mo Kio Park was the showcase project for the ABC Waters programme; its popularity eventually raised political will for similar projects elsewhere.

Bishan-Ang Mo Kio Park was developed to swell during torrential rainfall events (above) and return to normal levels after (below).

Integrating ABC Waters into new buildings: Kampung Admiralty

Completed in 2017, Kampung Admiralty is an integrated public development that brings together a mix of facilities and services under one roof. The compact 0.9 ha site with a height limit of 61 m, prompted a layered 'club sandwich' approach to design. Kampung Admiralty featuring featuring residential, commercial and social facilities co-located with a medical centre, hawker centre , an active aging hub and a childcare centre as well as community plaza, community farm and community park. Its unique tiered design showcases the various features at different levels of the building. This programme showcased the potential of maximising land use potential by integrating uses. A success of inter-agency collaboration, which saw HDB partnering with various agencies such as the Ministry of Health (MOH), Yishun Health Campus, National Environment Agency (NEA), the Early Childhood Development Agency (ECDA) and NParks.[68] Due to this integration, it was possible for HDB to incorporate ABC Waters design features into the new development.

For example, there is a harvesting system with a storage and irrigation tanks at the second and ninth storeys respectively to collect and treat rainwater runoff for reuse such as to irrigate landscaped areas within the developmen. Any overflow from this storage tank is piped to the cleansing

Developments, such as this in Kampung Admiralty, had water harvesting tanks built in from the start to promote water sustainability.

biotope where further filtering takes place and clear water will be discharged through a vegetated swale into the eco-pond behind the stage of the community plaza at the ground floor. Despite the development's small footprint runoff from about 33% of the site area is channelled into ABC Waters design features for temporary detention and treatment.[69]

The successful development of Kampung Admiralty showcases the possibility of integrating ABC Waters design features in new developments. Similarly, it points to the potential of encouraging more private developments to adopt such features to manage urban runoff at a local scale. Such localised efforts of managing urban runoff can be tailored to site-specific conditions and might be more feasible than large-scale infrastructure upgrading. From the case studies, it is evident that localised efforts have a role to play in complementing large-scale infrastructure plans and in tackling challenges at an urban systems level.

Kampung Admiralty features extensive rooftop gardens which detain water for use, slows runoff and hence reduce flooding.

Building flexible infrastructure

As a result of climate change, flood protection specialists are increasingly being forced to consider the interdependencies of urban infrastructure systems, particularly as lines of responsibility become more blurred. In certain situations, where climate risk is minor but extra costs are required to make the infrastructure system completely flood-proof, flexible infrastructural solutions are key to dealing with changing rainfall patterns and climate uncertainties. These solutions may range from flood-resistant construction materials to larger solutions such as enhancing drainage capacities and constructing protective berms along coastal roads when flooding becomes more pronounced. In the case of Rotterdam, climate adaptation and urban design were first linked together in Water Plan 2, a joint strategy involving the city and three water boards.

As opined by an engineer from Rijkswaterstaat, an executive agency at the Ministry of Infrastructure and Water Management:

> *We have to re-educate our engineers, because our engineers are educated in a linear world—things are true or not true. They learn to discuss risks, but they didn't learn to discuss uncertainty. So, that's a way of thinking that they didn't learn.*[70]

Singapore has embraced a holistic approach to stormwater management—the "source-pathway-receptor" approach, which utilises a catchment approach to better manage urban runoff. By managing the flow of stormwater beyond canals and drains (pathway), flood risk can be significantly reduced and managed, especially since there are limits to the continual expansion of existing drainage systems. Such an approach aims to integrate stormwater management solutions into developments and provides a degree of flexibility for the existing drainage system. By working closely with developers to encourage the installation of source solutions (e.g. decentralised detention tanks and ponds, raingardens, etc.) and receptor solutions, stormwater runoff is better managed and, in turn, developments are protected from floods.

Stamford Diversion Canal & Stamford Detention Tank

On 16 June 2010, more than 100 mm of rain fell in a two-hour period, resulting in flash floods on Orchard Road.[71] This resulted in property damage due to flooding in basements. Orchard Road again experienced flash flooding in December 2011, when over 152.8 mm of rain fell in a span of three hours.[72] These resulted in approximately S$23 million in insurance claims, damage to reputation and loss of public trust.[73] With more frequent and intense heavy rainfall events projected, authorities looked for solutions to enhance flood protection.

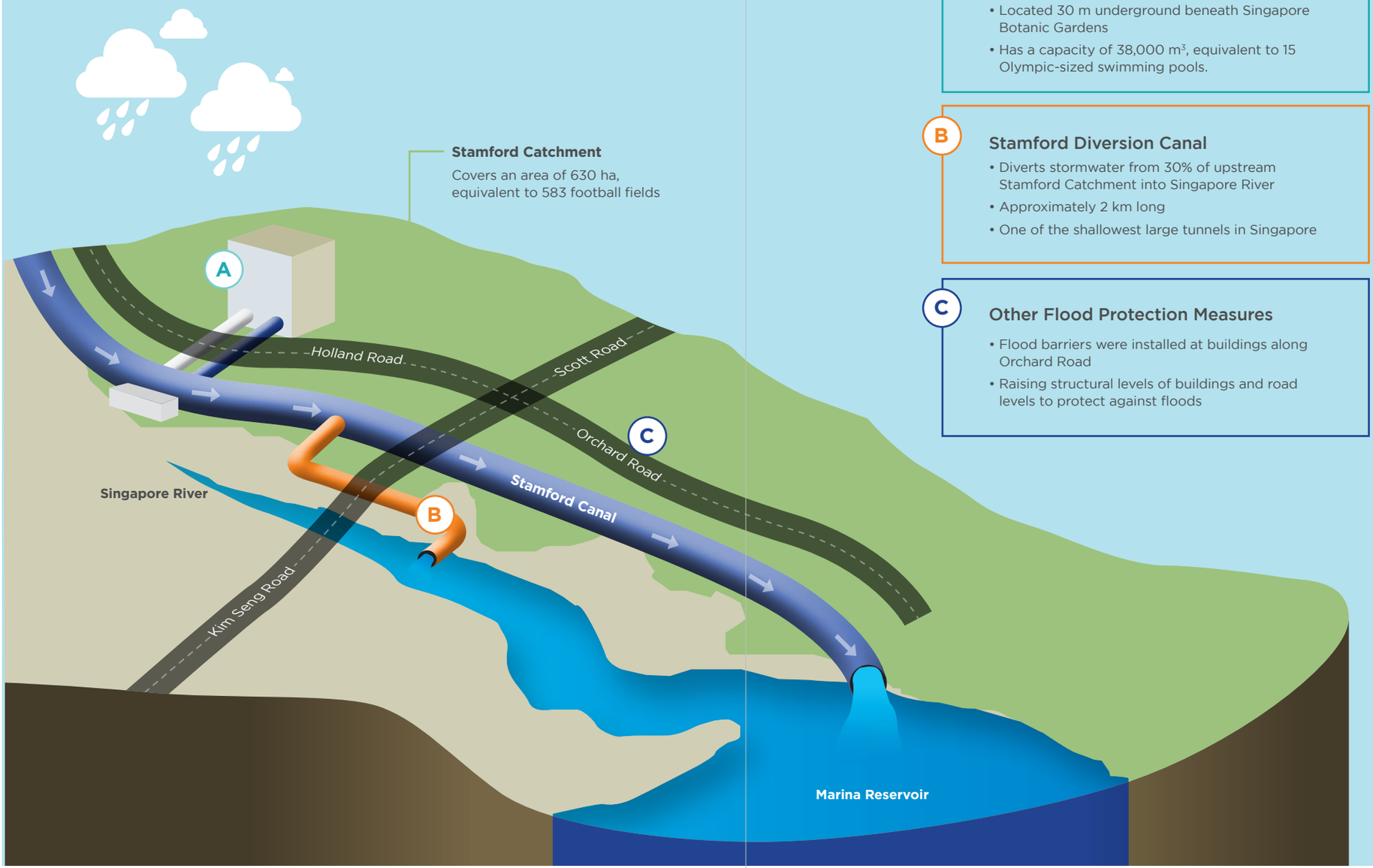
Orchard road was inundated during an exceptional flooding event in 2010.

The Orchard Road belt is served by the Stamford Canal, which was deepened and widened in phases between the 1970s and 1980s. However, such expansions are no longer possible as the middle and downstream sections of the canal are located in built-up areas.[74] Hence, to minimise disruption to the public and business owners, PUB looked for alternative solutions.

Laying out the plans

In the aftermath of the 2010–11 Orchard flash floods, the Ministry of the Environment and Water Resources (MEWR) appointed the Expert Panel on Drainage Design and Flood Protection Measures to review flood protection and risk management measures. The panel found that increasing the Stamford Canal's drainage capacity to address flood risk was not feasible and recommended to detain, reduce and delay runoff from the upstream catchment, as well as diverting excess flow to adjacent catchments.[75]

FLOOD PROTECTION MEASURES FOR ORCHARD ROAD



A **Stamford Detention Tank**

- Holds back excess stormwater during heavy rain
- Located 30 m underground beneath Singapore Botanic Gardens
- Has a capacity of 38,000 m^3, equivalent to 15 Olympic-sized swimming pools.

B **Stamford Diversion Canal**

- Diverts stormwater from 30% of upstream Stamford Catchment into Singapore River
- Approximately 2 km long
- One of the shallowest large tunnels in Singapore

C **Other Flood Protection Measures**

- Flood barriers were installed at buildings along Orchard Road
- Raising structural levels of buildings and road levels to protect against floods

PUB thus built a detention tank and diversion canal, which was completed in 2018.[76] The 2-km long diversion canal connects the upstream section of the existing Stamford Canal to the Singapore River, and leads to the Marina Reservoir. This approach will help in managing runoff within the catchment. Complementing the diversion canal is a detention tank located 30 m underground, with a capacity of 38,000 m^3 (equivalent to 15 Olympic-sized swimming pools) to temporarily hold stormwater runoff. As NParks was developing a new arrival area with coach parking for the nearby Learning Forest, PUB worked with NParks to co-locate the detention tank with the proposed coach parking. Together, the two projects divert the flow of runoff in the upstream catchment, avoiding the Orchard road shopping belt. The project was only possible through interagency collaboration (see Table below).

Construction of the Stamford Diversion Canal and the Stamford Detention Tank took four years and cost approximately S$227 million, but has to potential to ease the load on Stamford Canal by about 30% and protect Orchard Road, should similar scenarios reoccur.[77]

Roles of agencies involved in the eight-year planning and construction of the Stamford Diversion Canal and Stamford Detention Tank.

Agency/Organisation	Role
PUB	Planning and construction of detention tank and diversion canal.
NParks	Construction of linear park directly above the Stamford Diversion Canal, an important linkage to Kim Seng Park along the Singapore River. Facilitated the co-location of the Stamford Detention Tank with a coach park serving the Learning Forest extension of the Singapore Botanic Gardens. The tank sits 30 m below the coach park and its aboveground facilities are integrated with the coach park.[78]
LTA	Managed traffic diversions and development of new rail lines (Thomson East Coast line) in Orchard.
Orchard Road Business Association (ORBA)	Minimised disruption to visitors at Orchard Road.
Utility agencies	Manage underground cables and pipelines.

Stamford Diversion Canal (bottom) and the inside of the Stamford Detention Tank (top).

Climate-proofing neighbourhoods

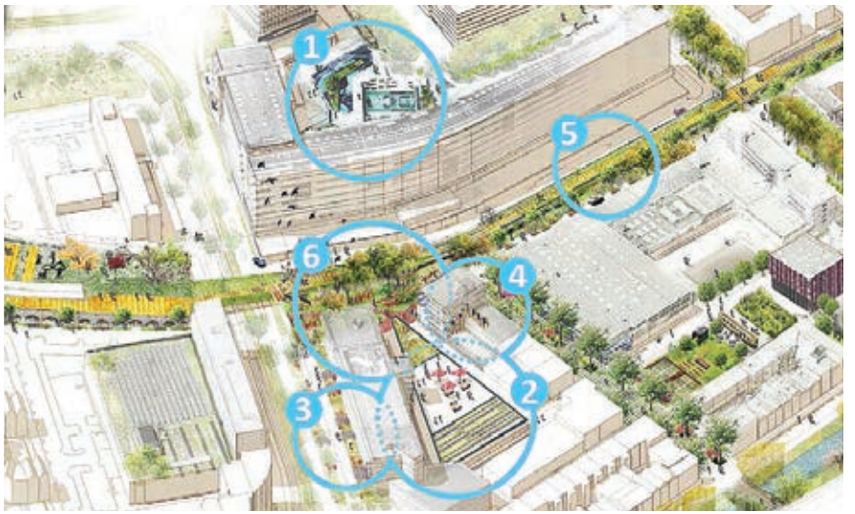
Climate-proofing can be a catalyst for realising attractive public space as climate-adaptive infrastructure should not only focus on clearing water away during tidal flooding and peak rain events but also identify opportunities to improve quality of life through vibrant public spaces, water features and water recycling. Such neighbourhood-level approaches create much-needed visibility to gain political and public support for similar projects in the future.

Zomerhofkwartier/ZOHO (Rotterdam) and Punggol Waterway Ridges (Singapore) are two neighbourhood-level projects that demonstrate how authorities can overcome traditional mindsets in designing infrastructure and work with various stakeholders to holistically manage stormwater runoff and create a more liveable environment.

Zomerhofkwartier (ZOHO)

Rotterdam is divided into 43 districts, each comprising several neighbourhoods. In the Noord district lies the ZOHO neighbourhood, a former industrial/business area just outside of the city centre where many older commercial and residential buildings are slated for redevelopment. Over the last decade, housing corporation Havensteder, which owns over 10,000 houses in adjacent areas, bought most of the buildings in the area with the intention to redevelop ZOHO into a residential zone.[79] In the meantime, start-ups in the creative sector, including architects and designers, temporarily occupy multiple buildings.

Paved surfaces in ZOHO were converted to raingardens to reduce heat island effect and address excessive rain events.



A total of six climate-proof solutions in the ZOHO neighbourhood: 1) Benthemplein water square; 2) polder roof; 3) Katshoek Rain(a)way Garden; 4) rain barrel; 5) Greening Hofbogen; and 6) raingarden.

As ZOHO experiences excessive rain events and intense periods of heat stress due to large amounts of paved surfaces and an old sewage system, it was a prime location to introduce climate-proofing measures. ZOHO was to serve as a blueprint for climate-proofing other neighbourhoods in the city, as 10% of the area of new developments or redevelopment projects in Rotterdam must be allocated for surface water retention using green-blue solutions.[80]

Urban regeneration efforts in ZOHO in the mid-2000s provided opportunities to pilot small-scale solutions such as rain barrels. In 2017, a sewage renewal project of part of the ZOHO, which brought together citizens and local businesses, was used to climate-proof public spaces and transform unused parking spaces into a raingarden.

In 2007, Water Plan 2 highlighted that addressing water issues was important for the city's quality of life, and initial funding was secured to try out ideas to retain more water in the city. While underground tanks are an effective measure for water storage, they are not cheap and are perceived as less effective in the eyes of taxpayers as they are not visible to the public. Therefore, the municipality adopted a strategy that located new water-storage solutions on the surface to make them visible and allow them to contribute to the environmental quality of urban areas, as well as strengthen neighbourhood identities and offer recreational spaces to citizens.[81]

In 2011, one of the first climate-proof solutions, the water square, was kick-started by landscape architect firm De Urbanisten, which brought together a diverse group of about 30 participants from the surrounding schools, church, theatre, gym and Agniese district to rethink the design of Benthemplein. In 2013, the city of Rotterdam, social housing corporation Havensteder and entrepreneurs came together to apply for a 100,000 euro (S$155,000) grant provided to address redevelopment projects in the area. Instead of redeveloping their property in the area themselves, Havensteder also partnered with Stipo, a local public developer, which agreed to move into the area. In the existing buildings owned by Havensteder, tenants were invited to pitch ideas that improve the social welfare of the adjacent neighbourhoods. Tenants also enjoy flexible lease contracts averaging two years, maintenance and have a say about their co-tenants.[82] One example of such creative contracts is among tenants of the Yellow Building, where rental is as low as 5 euros/m^2 (S$7.74/$m^2$). While 25% of rental proceeds go towards building maintenance, the first 25,000 euros (S$38,695) collected from tenants went back into redeveloping the ground floor space for place-making.[83]

Benthemplein water square on a sunny day.

As part of ZOHO's redevelopment process, the municipality saw a chance to invest in public space and while contributing towards climate adaptation goals. With the help of the municipality and Stipo, De Urbanisten organised a series of workshops to determine climate adaptation projects for ZOHO. Arising from the workshops, the creative studio located at Hofbogen Post Office (at Hofbogen Station, part of the former railway line) started the Green Hofbogen initiative by offering its frontyard to pilot climate-proof solutions. In turn, the Post Office coordinated the place-making process with the support of the Friends of the Hofplein Line group, while De Urbanisten advised on the water system design process and provided extra funds for construction.

One of the first climate-proof solutions arising from the workshops came from Studio Bas Sala, located in the Yellow Building, where a rain barrel was conceptualised to catch, store and reuse rainwater from the roof of Hofbogen Station, while reducing the direct flows into the sewage system. The idea was supported by the Netherlands Enterprise Agency, which provided a subsidy of 46,000 euros (S$71,000) to develop a prototype. The rain barrels are also connected to a solar-powered smart system developed by the Technical University of Delft.[84] The smart system monitors the weather forecast online. If heavy rainfall is predicted, the rain barrels will automatically release stored rainwater into the garden, so it has the capacity to collect new rainwater.

One of the water squares after a downpour.

Climate-proof recreational sites in Rotterdam.

During long periods of drought, water from the barrels is released to the garden. Moving forward, a smart rain barrel programme will be rolled out across different locations in the city, with a priority given to areas next to schools or community centres. Besides storm water storage and reuse, the rain barrels will also be used for education and communication purposes.

Developing Rotterdam's first climate-proof neighbourhood

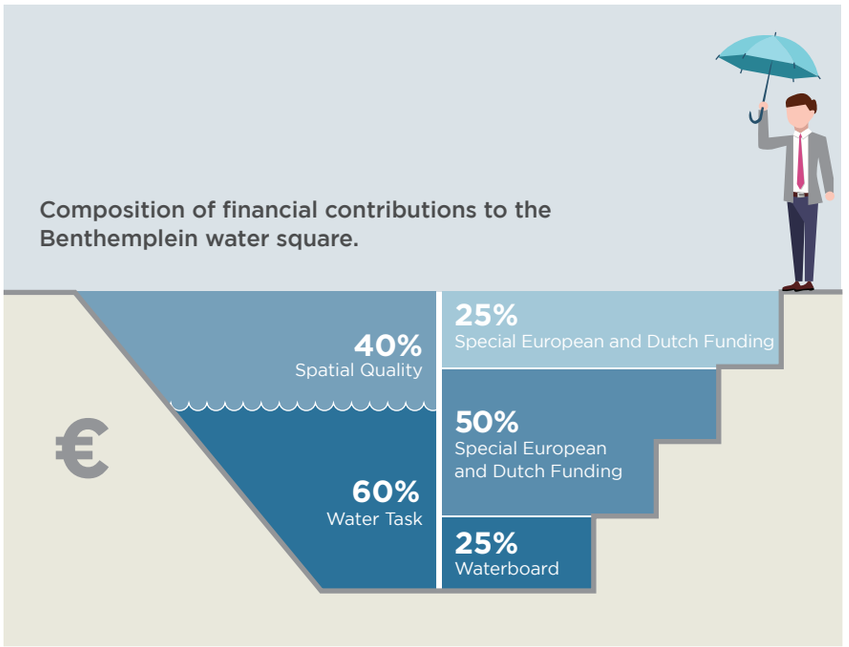
Roads and unused parking spaces near Hofbogen Station were also transformed into raingardens, where excess rainwater that falls on the pavement, garden or roof of the station would flow towards a deeper part of the garden. In this temporary pond or bioswale, the water infiltrates to the bottom of the garden and eventually into the soil. Apart from reducing the amount of impervious surfaces, these raingardens are multifunctional and can be used as recreational spaces during dry periods. The first raingarden pilot was kicked-off with the District Manager of Noord de-paving two parking spaces and replacing them with plants provided by the municipality.[85] To increase the number of raingardens in ZOHO, the municipality allocated 500,000 euros (S$774,000) for greening projects. Maintenance of the raingardens is estimated at 4,000 euros (S$6,200) per year and is carried out by the citizens.

Benthemplein water square, Greening Hofbogen Initiative, rain barrels and raingardens comprise more than half of the six climate-proof solutions implemented at ZOHO to date. Other innovations include the polder roof (transformation of the Katshoek parking garage roof to a green roof) and the Katshoek Rain(a)way Garden, where specially designed tiles are integrated into the pavement to slow rainwater runoff into the ground. Together, these projects not only help climate-proof ZOHO, but are also improving liveability and attracting investments to the once-derelict neighbourhood. Subsequently, the municipality received a sizeable European Union subsidy to further develop the ZOHO district.[86]

Collaboration between the neighbourhood and the municipality

The coordination of the various projects in ZOHO required the neighbourhood and the municipality to work together. A ZOHO programmer was initially appointed by Havensteder to re-programme the existing urban scape and take a bottom-up approach to planning. Meanwhile, the production of the raingarden and the rain barrels were collectively carried out by the municipality together with Havensteder, the neighbourhood of Rotterdam Noord and volunteers within the area, who collectively are known as ZOHOcitizens. This collective consists of approximately 50 volunteer entrepreneurs, citizens and investors, whose goal is to make ZOHO a better place to live, work and play.

The most characteristic project in ZOHO—Benthemplein water square—required greater co-ordination due to the various stakeholders involved. Benthemplein initially faced resistance from residents who were concerned with the safety of the open detention features as schoolchildren in the vicinity could fall into the square when flooded. Different agencies are also involved in the implementation of water squares as it entails the redevelopment of public space, which falls under the municipality's responsibility, while also working towards the objectives of the water boards, which are the main institutions dealing with flood risk. Eventually, a decision was reached to fund the water square from various sources due to the multiple objectives achieved (see illustration below).



The Frederiksplein water square is a co-creation of the city of Rotterdam, the water boards and the children living around the square.

Benefits

A range of climate-proof solutions collectively make ZOHO the centrepiece of Rotterdam's climate adaptation efforts. While ideas for some projects such as the rain barrels came from the creative community, others such as Benthemplein required a more top-down approach. After the economic crisis, water squares were seen as too expensive to be implemented, so there was a shift in approach towards more integrated squares designed and implemented with private and public sector support. This integrated approach required accommodating the interests of various stakeholders, resulting in greater social cohesion.[87]

The Frederiksplein water square in the climate-proof neighbourhood of Crooswijk (see image above) was designed using this approach. A former grey space, it was fully transformed in 2016 into an attractive sports field that retains and infiltrates rainwater. The design of the square was co-created with residents and students of the local primary school and implemented by the municipality and the water board of Schieland and Krimpenerwaard. Frederiksplein helps to limit flooding of streets during heavy rain showers with its ability to "absorb" rain showers of up to 20 mm directly into the soil through its infiltration system (porous lava stones that allow infiltration of rainwater into the soil at a slower pace). During heavier rainfall (more than 20 mm), the square serves as a water retention facility. When the square is dry, the residents and students in the neighbourhood can enjoy the green surroundings and a game of football or table tennis.

Punggol Waterway Ridges

The blueprint for Punggol was first unveiled in 1996, with the vision as 'A Waterfront Town of the 21st Century'. The aim was to develop a pioneer town of the new millennium, incorporating various new concepts, with high quality public housing, to meet the aspirations of Singaporeans. These concepts include planning based on smaller estates, new form housing integrated with carpark, integrated transport systems and recreational facilities for waterfront activities among other things.

Punggol was flanked by two rivers, Sungei Serangoon and Sungei Punggol, and there were plans to connect them to create freshwater reservoirs to increase Singapore's water supply. An underground pipeline was required to connect both reservoirs to balance water levels and this created an opportunity for HDB to introduce the 4.2 km long landscaped Punggol Waterway. It was subsequently opened to the public in 2011 and reinforced the vision of the town by bringing the waters closer to residents and opening up opportunities for waterfront housing and new recreational spaces.

In 2010, Punggol was selected to be developed as Singapore's first Eco-Town to enhance the living environment in its estates and encourage residents to do their part for the environment.[88]

Today, Waterway Ridges is one of the many housing precincts located close to Punggol Waterways. This precinct was conceptualised as the first housing project to integrate large-scale ABC Waters design features. It is bounded by the main Punggol Waterway and one of its tributary drains, with the design focusing on its unique waterfront setting and sustainable stormwater management. The project is the result of interagency coordination, with HDB working closely with PUB and a team of multidisciplinary consultants to make this water-sensitive precinct a reality. In this pilot collaborative project, a range of ABC Waters design features such as raingardens, bio-retention swales and vegetated swales were set among lush greenery. Bio-retention lawns that function as playfields on sunny days and a water plaza that celebrates treated rainwater as temporary water features after rain were also introduced. They were implemented at the precinct level to showcase the benefits of holistic stormwater management.

Punggol New Town was developed with a man-made river to connect two reservoirs. The town is popular due to its waterside characteristics.

Currently, ABC Waters design features form part of the natural drainage system that detains and treats stormwater runoff from about 58% of the precinct area. For example, runoff is stored in thick gravel layers below the features and discharged via orifices or control outlets to maintain a controlled amount of runoff using a targeted runoff coefficient of 0.55. The cleansed runoff flows into the Punggol Waterway and eventually into Punggol Reservoir and Serangoon Reservoir. The inclusion of the ABC Waters design features has also enhanced biodiversity while increasing the aesthetics of the housing precinct. The use of multifunctional design features also maximises land use. For example, the bio-retention lawns function as recreational spaces during dry weather but help detain and treat runoff during storm events.

As a pilot study, the overall drainage design takes a more cautious approach. For instance, more storage of stormwater, is provided in an additional layer of gravel beneath the rain garden and bio-retention lawn. Concrete drains were built to convey rainwater runoff during more intense storm events while the swales work to slow down and cleanse runoff from smaller storm events. The performances of the stormwater management strategies are currently being monitored in a study by the National University of Singapore and PUB.

Public green park connectors allow residents to have full access to the waterside, encouraging walking, cycling and appreciation of living with water.

Vision, design, and communicating effectively with stakeholders

The pilot collaboration on Waterway Ridges demonstrates the importance of having a clear vision from the outset, as well as a proper design with necessary pilots to test new design features and communication with stakeholders. For example, the development of the Waterway Ridges is in line with the broader vision for Punggol Eco-Town as a "sustainable waterfront town of the tropics".[89] This resulted in the development of a stormwater management masterplan/framework, which incorporates ABC Waters design features early into the planning and development of the housing precinct. In doing so, water quality and quantity issues are addressed early integrated into the planning process, instead of being an afterthought.

The masterplan/framework required strong collaboration between agencies, in this case PUB and HDB. Apart from designing energy-efficient buildings, innovative ways to mitigate climate change such as the adoption of water-sensitive urban design has also been suggested as a way of building more resilient infrastructure.[90] Waterway Ridges was one of HDB's early attempts to incorporate sustainable stormwater solutions, such as ABC Waters design features, into the development at the precinct level. As a masterplanner and developer, HDB is responsible not only for physically planning and designing public housing units, but also the entire town. The aesthetic of the precinct was inspired by scenes of mountains and rivers, resulting in the final design where the orientation and heights of the buildings were staggered to mimic ridges.[91]

Bridges, platforms and pathways allow residents to enjoy living with water.

Engaging the public and residents were also crucial in the development of Waterway Ridges. To enhance awareness, informative signage aimed at educating residents and visitors on ABC Waters design features can be found within the precinct. Some designs were tweaked to ensure social interaction among residents. For example, barrier-free design, combined with a network of footpaths and sheltered linkways, allow residents to safely enjoy leisurely strolls within the development, while plaza and viewing decks offer opportunities for social interaction among residents. These efforts bring people closer to water, increase awareness of climate change related issues and thus, ensure the long-term sustainability of these projects.

Benefits

The successful implementation of ABC Waters design at the precinct level showcases the potential of integrating a sustainable stormwater management system with urban development to better manage the climatic uncertainties that come with climate change. For Singapore, the challenge is adapting to frequent and intense rainfall events that result in higher peak flows. While drainage capacity can be improved, a more sustainable solution is to ensure new developments are fitted with multi-purpose spaces that can detain water and to incorporate water-sensitive design features to manage runoff at the source itself. By focusing on a larger development area—the neighbourhood level—and with upstream planning, such design features are implemented earlier and thus, work more efficiently.

Outreach programmes and communications

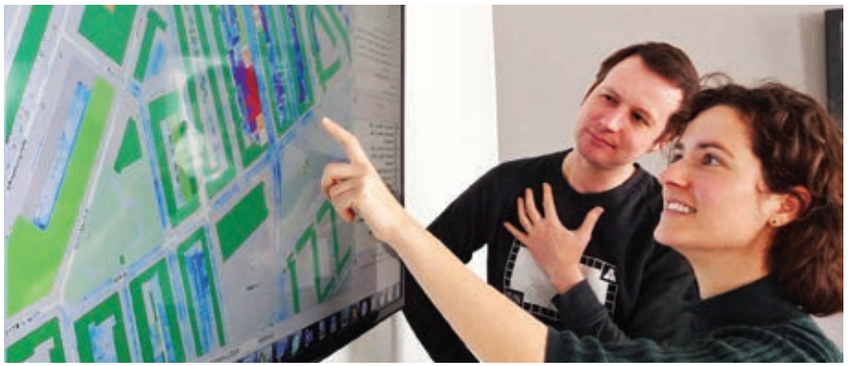
Apart from adopting flexibility in infrastructural policies and designs in dealing with floods and climate uncertainties, defining acceptable risk levels and appropriate responses with relevant stakeholders are also important. To empower the community to take action against flood and climate risks, physical infrastructure built for climate change adaptation also need to be complemented by programmes that raise the public's awareness. Beyond disseminating information, residents need to be encouraged to collaborate with authorities and the different stakeholders to take ownership and contribute to the development of climate-proof cities.

The Dutch way of collaboration is built around the centuries-old "polder model" of consensus seeking, which originated when farmers and landowners pooled resources and reached agreements on dike maintenance and water management within the polders.[92] In the early 2000s, the Dutch government raised the issue of water risks among citizens with a communication campaign using the slogan "the Netherlands is living with water":

> *Deltas with vast supplies of water make an attractive place in which to live, work and relax. But there are also inherent risks to living in low-lying regions; absolute safety cannot be assured and the possibility of flooding can never be eliminated. Government needs to make citizens aware of the risks. This will allow citizens to make their own contribution, alongside that of the government, to prevent damage and flooding.*[93]

Today, the polder model of consensus decision making is also practised in Rotterdam for climate adaptation projects as policies move from a flood probability approach to one that

Blue Label flood risk map used to highlight infrastructure (buildings and roads) at risk of flooding from rainwater. A=smallest risk, E=highest risk.



Rotterdam residents can use the Blue Label map to understand their flood risk and take individual initiative to adopt adaptive measures.

focuses more on flood risk, increasing the need to communicate risks to stakeholders.[94] The municipality commissioned the Blue Label project, a risk classification system to identify the risk of flooding for houses and roads, with the information made available to stakeholders on an interactive digital platform to encourage citizens to adopt flood mitigation actions.[95]

In Singapore, 90% of individuals said they were concerned about the effects of climate change on future generations.[96] Nevertheless, efforts to involve the community on climate change issues are nascent, with the Year of Climate Action, a year-long national initiative introduced in 2018 to narrow the gap between awareness and action. Individuals and companies are also encouraged to publicly declare their readiness to deal with climate change.[97]

Blue Label (Rotterdam)

Climate change is introducing climate-related risks for the urban environment. Extreme weather events are occurring more frequently and the impacts of these events are more dramatic than before. Heavy downpours can cause unexpected surface (pluvial) flooding when urban drainage and river systems can no longer cope with water volumes. It is crucial to understand and quantify these risks to be able to plan, implement and manage flood-resilient activities, from infrastructure and development to the daily running of lives and businesses.

For these reasons, an adequate understanding of flood risk is important. Blue Label, a private sector initiative by Achmea (the Netherlands' largest insurance company), Royal HaskoningDHV and Nelen & Schuurmans, provides insights into flood risks by offering the first digital water vulnerability scan in the world that gives detailed information on rain-induced flooding, down to the square metre. This translates into a risk level that is assigned to individual buildings, streets and infrastructure, which reflects the risk of flooding. Its aim is to encourage the public to be proactive in preventing disasters, rather than devising recovery measures in their aftermath.

Communicating complex issues

Blue Label hopes to raise public awareness about exposure to flood risk and so they can take mitigating actions. To achieve this, it harnesses smart technologies to make complex data visual, and thereby easy to understand. This is done without compromising accuracy: extreme rainfall events are analysed and used to calculate the risk of floods using hydrodynamic models. The information is publicly available online, and people can enter their addresses to view their flood risk and see if they qualify for subsidies to undertake the relevant mitigation actions. Meanwhile, policymakers are able to access a dashboard system funded by the municipality. Smart technologies that highlight areas vulnerable to flooding empowers governments, industries, organisations and homeowners to take action to mitigate the risks of rainwater flooding. These insights can be used to plan both small-scale and large interventions that contribute to greater flood resilience, thereby improving liveability.

Blue Label's risk levels are easy for non-experts to understand. Its reports are used to facilitate dialogue between stakeholders and citizens on potential risks. Collaborative efforts are essential as climate change challenges require integrated action. Blue Label's analysis allows authorities to monitor flood vulnerability patterns over time to make spatial and infrastructure planning more climate-proof and water-resilient. Blue Label's risk levels can be used to further develop responsible policy making and new flood protection standards that are linked to a risk-based approach.

Benefitting people, private and public sectors

Rotterdam is a global leader in water management and has an ambitious strategy for city resilience. It is the first Dutch city in the Netherlands Community of Practice (CoP) on Climate Adaptation to invest in the dashboard and provides pilot sites to test the labels and provide houses at-risk with financial assistance to implement more risk mitigation measures, with plans for the service underway in Amsterdam and Nijmegen.[98]

Insurance companies have information about damages specific to postal codes and house numbers. However, due to the Dutch law on privacy and protection of personal data, insurance companies are unable to share this information with policymakers. Nevertheless, they are able to share spatial information at the street level, which can be used by the municipality to get a more detailed map of vulnerable areas.[99] In turn, insurance companies also benefit by reducing payouts in the face of flood-related damages when residents undertake more mitigation measures, resulting in mutually beneficial outcomes for all.

Year of Climate Action (Singapore)

In 2016, Singapore released its Climate Action Plan, a national strategy to address increasing challenges brought about by climate change. The plan details both mitigation and adaptation strategies, with the latter highlighting measures such as managing water supplies and minimising floods in the face of changing rainfall patterns.

To encourage greater awareness on climate change and the need for climate action, the Ministry of the Environment and Water Resources (MEWR) designated 2018 the "Year of Climate Action" (YoCA). The main aim of YoCA was to highlight the urgency for climate action, and the need for a whole-of-society effort. In addition to working with industries, schools and NGOs to educate the public, a Climate Action Pledge was launched to rally individuals, companies and schools to publicly pledge steps that they would take as part of climate action.

Over 300,000 pledges were made during the year. Actions pledged by the community ranged from water conservation, purchasing Green Label products (eco-labelling scheme for consumer products), to reducing energy consumption at home. In addition, over 800 climate action related events were organised by the 3P (People, Private, Public) sectors to educate the public and galvanise action. These events included initiatives such as tree planting, energy-saving challenges, and sustainability-themed exhibitions and dialogues.

A Climate Action SG Alliance comprising leaders from 3P sectors was also formed, to lead ground-up initiatives targeting schools, businesses, and the general public. The Alliance embarked on three key projects in 2018, aimed at getting businesses to adopt sustainable practices, and to educate the public on the correct ways to recycle.

As the Chair of ASEAN in 2018 and the Chair of the ASEAN Working Group on Climate Change, Singapore convened the Special ASEAN Ministerial Meeting on Climate Action (SAMCA) and the expanded SAMCA in July 2018, where ASEAN Member States and Plus Three Partners—China, Japan and the Republic of Korea—reaffirmed the region's commitment to the Paris Agreement, and discussed ways to step up regional action to address climate change.

To sustain the momentum and awareness generated from the YoCA, a Climate Action Week comprising a series of ground-up initiatives by the 3P sectors was organised in July 2019.

More than 300,000 pledges were made during the Year of Climate Action, involving more than 800 programmes and events organised by the public, private and civic sectors in Singapore.

Future projects

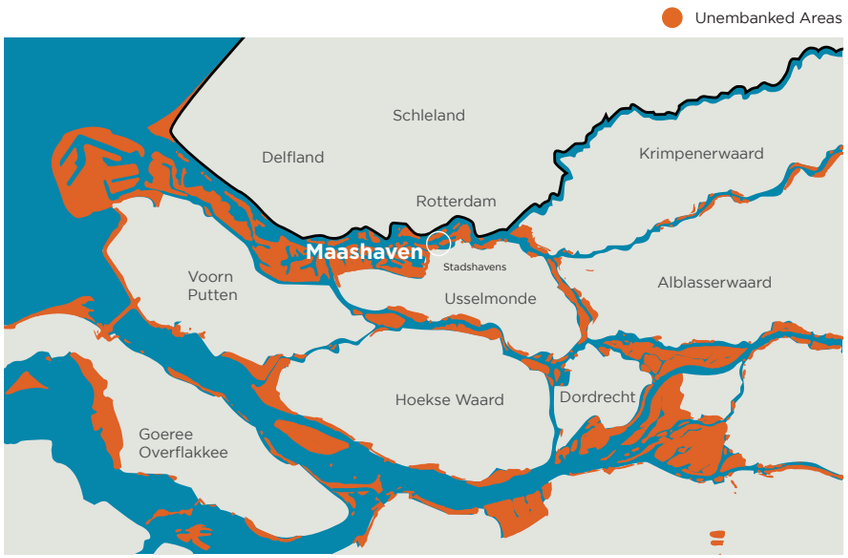
Both Singapore and Rotterdam are investing in projects that take into account projected changes in sea level, rainfall patterns and climate. The following are some examples.

Tidal Park Maashaven (Rotterdam)

Rotterdam's plans to redesign the city to accommodate more water and involve the community is encapsulated in the city's 2019 Rotterdam Weatherwise. Nevertheless, flood risks in Rotterdam are increasing due to restructuring and redevelopment of un-embanked areas. Even today, new developments in un-embanked areas are allowed in Rotterdam if elevated to a safe level. Much of the former port areas in the un-embanked areas of the city centre are due for redevelopment as the berths were relocated in 2018.

This is as a huge opportunity to create space for the development of tidal parks in a city where as much as 70% of the riverbanks are lined with hard quays and less than 10% have a natural tidal outline.[100]

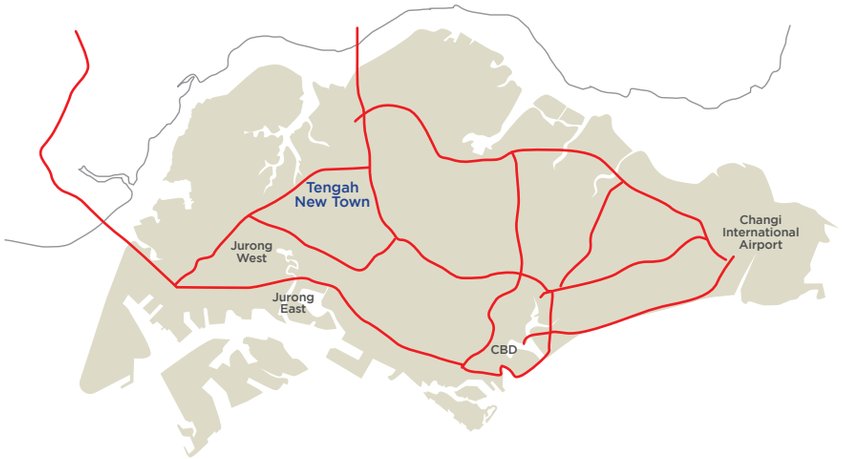
In 2017, the municipality set out its vision for Maashaven, situated in Rotterdam South in one of city's most densely populated districts, which has a lack of public green space. Thus, the development of a tidal park in Maashaven allows the city to achieve multiple goals: create a high quality of life for residents (an additional 5 ha of public green space) and improve ecology and water safety. Starting with the reallocation of the berths in 2018, the project will be implemented in phases over four years.



Vulnerability of unembanked (highlighted orange) waterfront areas in Rotterdam, showing Maashaven.[101]

Artist's impression of Tidal Park Maashaven.

Upon completion, it will also retain some characteristics of the old port area to reflect the city's history. Maashaven is envisaged to be a good living area as it is in close proximity to the expanded port area at Maasvlakte 2. As Maashaven is also an area outside of the dykes that is vulnerable to flooding by the river, the creation of the tidal park combines spatial developments with water safety, and has an educational value in bringing people closer to water and reminding them of the challenges of climate change. Lastly, the project allows Rotterdam to showcase Dutch expertise in water management and delta technology, nature, landscape development and landscape architecture, generating more economic opportunities in return.[102]



Approximate location of Tengah New Town in Singapore.

Tengah New Town (Singapore)

The 700-ha Tengah New Town is being developed by HDB as a green, biophilic, smart and sustainable town. Formerly populated with villages, fruit tree plantations and farms during 1950s, and later a military training site for the Ministry of Defence in 1990s, Tengah New Town is expected to house about 42,000 new homes when fully developed, with the first launch in the Plantation District in November 2018. The town will be designed with the community and nature in mind, so that residents can experience quality living with nature and greenery at their doorstep. This will be in line with Singapore's Smart Nation vision, as HDB strives to leverage and expand on smart technologies to bring about a better quality living environment for residents. Action plans and Key Performance Indicators (KPIs) have been developed for the systematic deployment of sustainable initiatives and tracking of outcomes.

Tengah New Town is a smart, sustainable town that will feature integrated green and blue infrastructure.

Artist impression only. Actual design may differ.

Tengah will be the largest town in Singapore to adopt the Smart HDB Town Framework, which includes the use of data and technology for planning, improving estate services and creating pleasant environments for residents. Among these is the Integrated Environment Modeller, which uses a 3D model to simulate microclimatic conditions throughout Tengah. It simulates the combined effects of wind channels, solar irradiance, greenery, water bodies, and building surfaces on temperature fluctuations to help design the town in a way that enhances natural ventilation.

The town also features an UrbanWater Harvesting System where the rainwater harvesting tank is co-located with the detention tank to slow down stormwater runoff and harvest rainwater for non-potable uses such as washing of common areas and irrigation. This centralised system is more cost-effective than building a rainwater harvesting system at each residential block. Other water-sensitive features include raingardens, bioswales, green roofs, roof gardens and a naturalised canal. Moisture sensors will also be used for smart irrigation.

Sungai Buloh wetlands has been designed to allow the public access to natural habitats with low impact to the environment.

4. PRINCIPLES AND KEY LESSONS

Drawing from the experience of Rotterdam and Singapore, researchers from the Centre for Liveable Cities (CLC) and the Rotterdam Office of Climate Adaptation identified several lessons on how cities can adapt to the impacts of climate change. These lessons illustrate the possibility of living with water, which includes building liveable cities while concurrently managing water issues like urban flooding and sea level rise.

Climate-proofing cities involves two fundamental principles: adopting multifunctional solutions, and taking a multi-stakeholder approach, as detailed below.

Principles

Adopt multifunctional solutions

In densely built-up cities, urban space is limited and precious. Therefore, mono use of land is less than ideal. With climate change, cities will increasingly face challenges associated with sea level rise and more frequent and intense extreme rainfall. Implementing drainage infrastructure in a business-as-usual way is unsustainable as they tend to be capital-intensive and pose challenges for expansion due to space constraints in built-up areas. The aim of building liveable, climate-proof cities is to ensure that land use is optimised, thus, yielding multiple benefits. The goal is to adopt an urban systems approach, where integrated planning and development through long-term foresight and innovation is possible, which enables the planning and development of multifunctional spaces for a liveable city.

However, such integrated solutions are not easy to implement. They require changes to the existing governance structure, complicating singular land use frameworks and ownership. They raise questions about financing mechanisms, ownership and accountability to the maintenance of these projects in the long-run. Nevertheless, multifunctional urban spaces are one of the core adaptation approaches used in both Singapore and Rotterdam, where urban space is being reimagined and adapted for changing climatic conditions.

Integrated solutions, such as rainwater squares, are only possible if planning guidelines and governance structures are updated to permit its development, and residents are made aware how to use them in a safe manner.

Involving stakeholders from various sectors in society is necessary to achieve greater resilience in communities.

Take a multi-stakeholder approach

For multifunctional solutions to work, dynamic urban governance in the form of a multi-stakeholder approach is fundamental. This includes breaking away from silos, working with markets and involving communities as stakeholders. To prevent silos, communication is required within water management departments and among other land use departments. The private sector plays a role in mainstreaming adaptation techniques into new or existing developments and can help finance adaptation projects.

While Rotterdam is a poster city for climate adaptation initiatives today, the city's journey did not begin with all stakeholders convinced of the need to take action. During the mid-2000s, visits to Rotterdam by global climate leadership groups C40 and the Clinton Climate Initiative convinced former Mayor Ivo Opstelten and the city to undertake actions to address climate change and prioritise climate adaptation.[103] In 2008, Rotterdam entirely funded the setup of the Office of Climate Adaptation (then Rotterdam Climate Initiative) with a budget of 31 million euros (S$48 million) and an initial staff strength of six city officials dedicated to adaptation planning, signalling the political priority that the climate policy programme enjoys.

Nevertheless, the responsibility for urban planning in Rotterdam remains spread across three different city divisions, while adapting for climate change is centralised under the Office of Climate Adaptation, hence posing challenges to the mainstreaming of adaptation into urban planning processes.[104] With the recent development of the Rotterdam Delta Program Climate Adaptation, the Office carries out monthly briefings to the different divisions and to the transportation and infrastructure departments to promote the need for climate action, which eases subsequent communications to various stakeholders, including the public, on the need to undertake action.

For adaptation to work, it is also important for the public to be involved. Moving forward, the public sector has to explore how to work closer with communities and develop more bottom-up approaches to climate-proofing cities. This includes building up the social resilience and social capital of communities living in flood-prone areas. By involving a range of stakeholders, the goal of building multifunctional spaces can become a reality.

Key lessons

Climate change is not only associated with disruptive events (e.g. storms or heatwaves), but also with the gradual impacts (e.g. rise in sea level or average global temperatures) that can still have severe consequences if no action is taken.[105] Hence, it is increasingly important in the planning of towns and cities. It requires mainstreaming adaptation solutions into existing urban planning processes, incorporating guidelines into building codes and making green and blue spaces work harder. This book has distilled several key lessons in integrating urban planning and climate change challenges, with a common goal towards building more liveable cities. We conclude our research with the following key lessons:

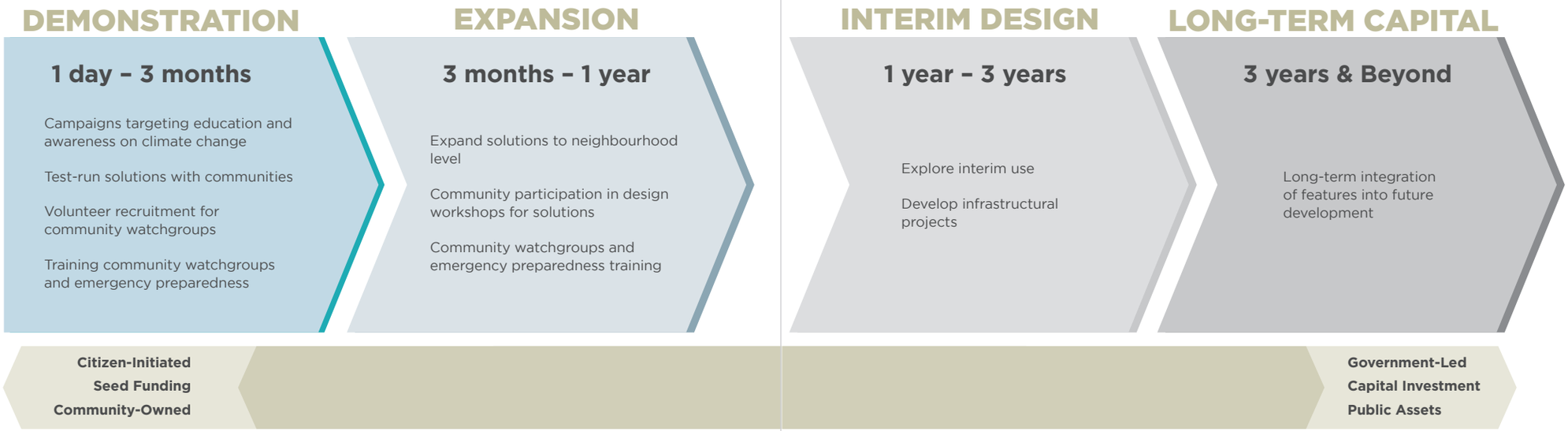
Scale solutions for success

Bigger is not always better. With adaptation techniques, it is important to scale the solution to cater to different circumstances. While major infrastructure projects can help cities cope with sea level rise or more extreme rainfall, these tend to be capital intensive and take time to be constructed. In addition, the uncertainty associated with climate change and its impacts also makes it difficult to plan for such major projects. Hence, there is a role for smaller-scale adaptation solutions that can work at an urban systems level to complement larger infrastructure projects and mitigate the impacts of climate change. This can include the development of more

neighbourhood-level projects like the ZOHO district in Rotterdam and Punggol Waterway Ridges in Singapore.

Where cities may not have the luxury of working at the neighbourhood level, adaptation solutions can be built into new developments. For example, to address inland flooding, new developments could integrate solutions that control runoff, working to eventually contribute to water management in the entire catchment. Singapore's ABC Waters programme and Rotterdam's Green Roofs programme are examples of localised efforts to manage water.

Innovation is also vital to integrate water-sensitive urban design in urban places, reinforcing the idea of "living with water". Research should be carried out on the long-term operational, maintenance and performance of water-sensitive design elements. Where proven to be sustainable and effective, they elements can be mainstreamed into storm water quality management practice and guidelines. Netherlands' TKIs, for example, have helped to accelerate pilots on climate-proofing solutions.



An example of planning for small-scale projects at an urban systems level to involve diverse stakeholders in climate change adaptation.

Build in flexibility

Due to the uncertainty about the impacts of climate change, flexibility is needed in devising innovative, adaptable solutions for cities. This includes solutions previously deemed unsustainable due to unfavourable conditions (e.g. lack of support or finance). Building in flexibility also means future-proofing the plans. Communication among stakeholders and periodic reviews are important to ensure plans are able to adapt to changing circumstances. For example, when the Bishan-Ang Mo Kio Park in Singapore was due for routine refurbishment, PUB and NParks decided to reimagine the outcomes, resulting in the concrete canal being reconstructed as a meandering river. This would not have been possible without the willingness of the agencies to work together to adapt their plans to the changing circumstances. The redevelopment of the ZOHO district in Rotterdam is another example. There too, authorities seized the opportunity to redevelop innovatively when the sewage system was due for refurbishment, thereby not only addressing the flood risks, but also heat. The involvement of citizens and businesses in the redesign also ensured public awareness of climate impacts increased.

Use innovative financing

Financing suitable and impactful projects is a challenge in most cities. In Rotterdam, convincing people to fork out additional funds to support climate-proofing solutions is a challenge as residents already pay a sewage levy for the collection and processing of rainwater. While the operations of the Rotterdam Office of Climate Adaptation is primarily funded by the Dutch government, it has been able to facilitate climate-proof solutions by harnessing private investment.[106] One way is by encouraging the adoption of climate adaptation measures in building regulations for new projects or renovations.[107]

In the cases of ZOHO and Robert Fruinstraat, sewage renewal opportunities served as catalysts for incorporating climate-proof solutions. To get buy-in from the people sector (e.g. private homeowners), municipalities funded up to 25% of building-level measures such as green roofs or raingardens in the form of subsidies.[108] To encourage industry participation, the Netherlands Enterprise Agency funds research pilots to encourage TKIs to collaborate in public-private partnerships. In these, TKIs receive 25 cents for every euro invested by the industry in R&D with a research organisation.[109] This co-funding model was instrumental in supporting ideas from the industry, including the rain barrel development in Hofbogen and the urban water buffers at Robert Fruinstraat.

Recognise the potential of intangible benefits

While many adaptation solutions can be capital intensive, it is important to consider the intangible and multiple benefits that are accrued beyond climate adaptation. In the case of the Green Roofs programme, a social cost-benefit analysis was carried out as part of the in-depth analysis to determine benefits beyond slowing down stormwater runoff, such as improved cooling effects of surrounding environments, aesthetic values, and more. Nevertheless, certain benefits are difficult to quantify (e.g. improved productivity of workers exposed to greenery). However, in the process of gathering data and adopting an evidence-based approach to justify expenditure on climate adaptation solutions, intangible benefits should also be considered in totality. For example, the Frederiksplein water square in Rotterdam was a costly infrastructure project and requires ongoing maintenance. However, as it was designed together with the residents of Crooswijk and students of the local primary school, it has become an attractive meeting place for people in the neighbourhood.

It is also important to examine the costs of such adaptation features over time. While expensive upfront, costs arising from infrastructure damage due to flooding is reduced. Maintenance costs also may go down, thus balancing out expenditure in the long run. Moreover, the ABC Waters design features provide multiple ecosystem services such as enhanced biodiversity and new recreational spaces.

Involving residents and businesses in the redesign of neighbourhoods raises levels of awareness on the impacts of climate change, thereby improving community resilience.

Involve the community to encourage ownership

Finally, community resilience cannot be built without its involvement in actions. While it may be easier for cities to focus on "hard" solutions (i.e. infrastructure) when it comes to adapting to climate change, cities should consider how to involve communities in the planning and decision-making process as neighbourhoods undergo climate-proofing. Would a more bottom-up approach be better for climate-proofing initiatives? Building up social resilience to prepare communities to adapt to the impacts of climate change are important "soft" solutions that must be developed.

In the case of Rotterdam, while there are 42 neighbourhood directors that help authorities communicate plans to the public, platforms for community participation were also created to ensure the sustainability of climate-proofing initiatives. The CoP on climate adaptation brings together the local community and practitioners to develop solutions and communicate complex issues using digital tools such as Blue Label on flood risk to the public.

Beyond helping to involve the community at the building and house level, streets and neighbourhoods also have networks of residents (e.g. ZOHOCitizens, StraaDkrant) that can organise their participation in the design process of climate-proofing solutions. With the development of Robert Fruinstraat, community involvement was crucial in pushing for the development of urban water buffers. Although it was illegal for Water Sensitive Rotterdam to support climate adaptation on private land, it was in the public interest to climate-proof Robert Fruinstraat.[110] Community participation in the conceptualisation of what actually makes the street liveable and areas for improvement were crucial to the design of Robert Fruinstraat. Seventeen people from almost 60 addresses on the street indicated their willingness to contribute ideas for its future. This group of committed residents were involved in workshops on themes such as greenery, water, energy and social cohesion as part of climate-proofing the street.[111]

Similarly, in Singapore, residents have been involved in the design of parks as more of them incorporate ABC Waters design features in their redevelopment. As many redesigned parks are situated in public housing estates, authorities worked with residents on design elements and address concerns pertaining the safety of the waterways. Authorities also leverage these networks to educate the public on using parks in a responsible and safe manner. Hence, combining technical innovations and integrated planning across different agencies with a more receptive public and more participatory process can help ease trade-offs and manage resource use in infrastructural projects. A collaborative approach that strengthens the working relationship among stakeholders is paramount to the success of future projects as communities can better understand and appreciate proposals. This could lead to a more adaptive and resilient population in the face of climate change.

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Abbreviations

ABC Waters	Active, Beautiful, Clean Waters
ASEAN	Association of Southeast Asian Nations
CDC	Connecting Delta Cities
CLC	Centre for Liveable Cities
CoP	Community of Practice
ECDA	Early Childhood Development Agency
HDB	Housing and Development Board
IABR	Architecture Biennale Rotterdam
IEM	Integrated Environment Modellers
JTC	Jurong Town Corporation
KPI	Key Perfomance Indicator
LTA	Land Transport Authority
MEWR	Ministry of the Environment and Water Resources
MOH	Ministry of Health
NEA	National Environment Agency
NGO	Non-Government Organisation
NParks	National Parks Board
ORBA	Orchard Road Business Association
PUB	PUB, Singapore's National Water Agency
RCP	Rotterdam Climate Proof
SAMCA	Special ASEAN Ministerial Meeting on Climate Action
TKIs	Top Consortia for Knowledge and Innovation
URA	Urban Redevelopment Authority
UWHS	Urban Water Harvesting System
WSR	Water Sensitive Rotterdam
YoCA	Year of Climate Action
ZOHO	Zomerhofkwartier

Glossary

Meerlaagseveiligheid	Multilayer flood-risk management approach by employing flood prevention measures and reducing the city's flood risk through spatial planning and urban design.
C40	C40 is a network of the world's megacities committed to addressing climate change. C40 supports cities to collaborate effectively, share knowledge and drive meaningful, measurable and sustainable action on climate change.
LIFE	LIFE is the European Union's (EU) financial instrument to support environmental, nature conservation and climate action projects throughout the EU at the regional, multi-regional or national level since 1992.