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Achieving a Water-Resilient Rotterdam: Past, Present and Future Perspectives

Nanco Dolman
Deltares
Johan Verlinde
Municipality of Rotterdam

Rotterdam has a close and essential connection with water, both as a port city and a delta city. As a low-lying city situated in the estuary of the Rhine and Meuse Rivers, most of the city (85 per cent) lies below sea level, and some areas are as low as 7 m beneath sea level. Except for the main port area, the remaining 15 per cent of the city lies in outer dike zones. Since evacuation is nearly impossible, adapting to climate change presents a significant challenge. This vulnerable delta city is continually revisiting its approach to water threats and climate change is demanding a new round of interventions. The historical fight against water is being abandoned in favor of living with water. Water connects and brings leverage. By creating more space for water and promoting blue-green infrastructure in the built environment, Rotterdam is becoming climate-resilient, greener and more livable. Rotterdam's blue-green transformation to a sponge city of the future (2100) aims at achieving SDG 11 (Sustainable Cities and Communities) and has the potential to fulfill targets regarding climate action (SDG 13), the protection of water quality (SDG 6) and the restoration of biodiversity (SDG 14 and 15).

Keywords: *blue-green infrastructure, climate adaptation, sponge cities, water resilience, water urbanism*

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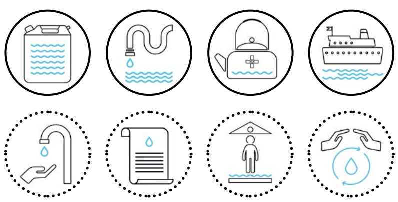
KEY THEMES



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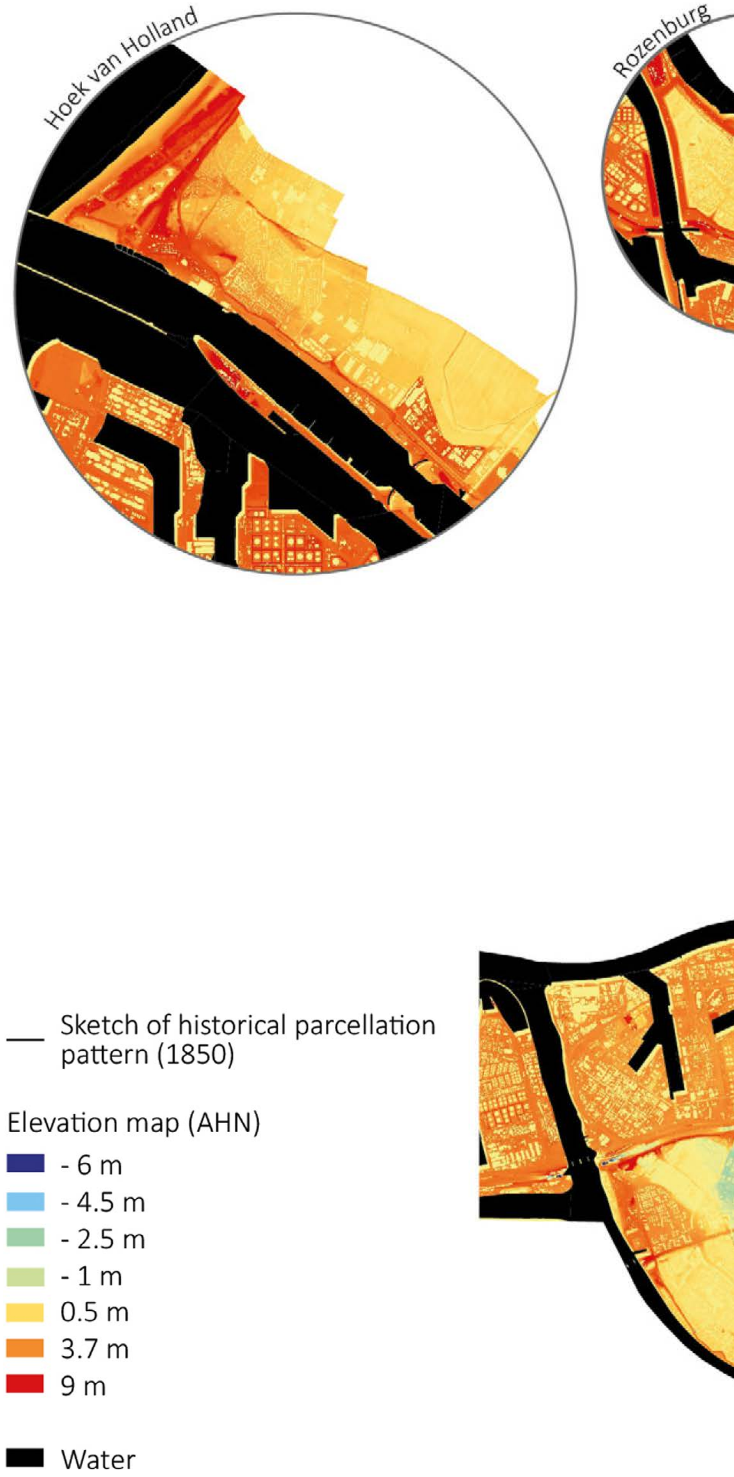
< Fig. 1 Impression of live on the Meuse and the city could look like in 2100 (Source: De Urbanisten 2022).

The Past: From Fighting Water to Living with Water

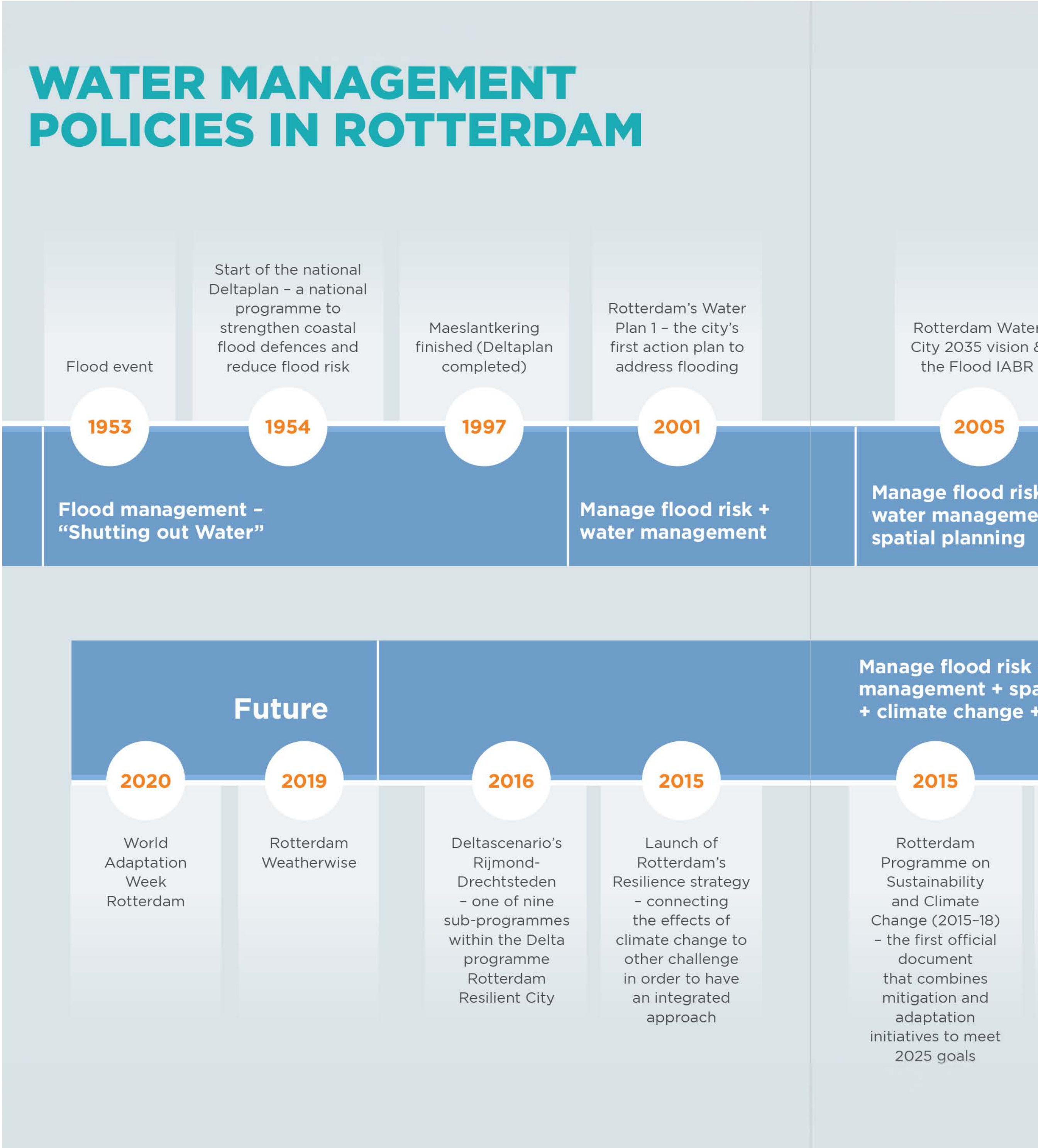
Controlling water has always been a theme in Rotterdam's urban development (Van Vliet and Aerts 2014) and one that is evident in its strategic location along the Nieuwe Maas River, a tributary of the Rhine. Today, Rotterdam faces challenges associated with rising sea levels, high river discharges and extensive polders below sea level (fig. 2), highlighting its vulnerability to water-related hazards. Situated in the Rhine-Meuse estuary of the Netherlands, Rotterdam originated from a dam on the Rotte River in the thirteenth century. Once a small fishing village, it is now a prominent international port city and the largest port in Europe.

As Rotterdam's port thrived, attracting more residents, urbanization brought new challenges. Densely populated areas saw waste and sewage dumped into ditches, leading in the nineteenth century to sanitation issues and cholera outbreaks. Architect Willem Nicolaas Rose responded with "The Singel Plan," constructing canals to flush the city with fresh river water in 1854. This plan improved citizens' health and made the city more attractive.

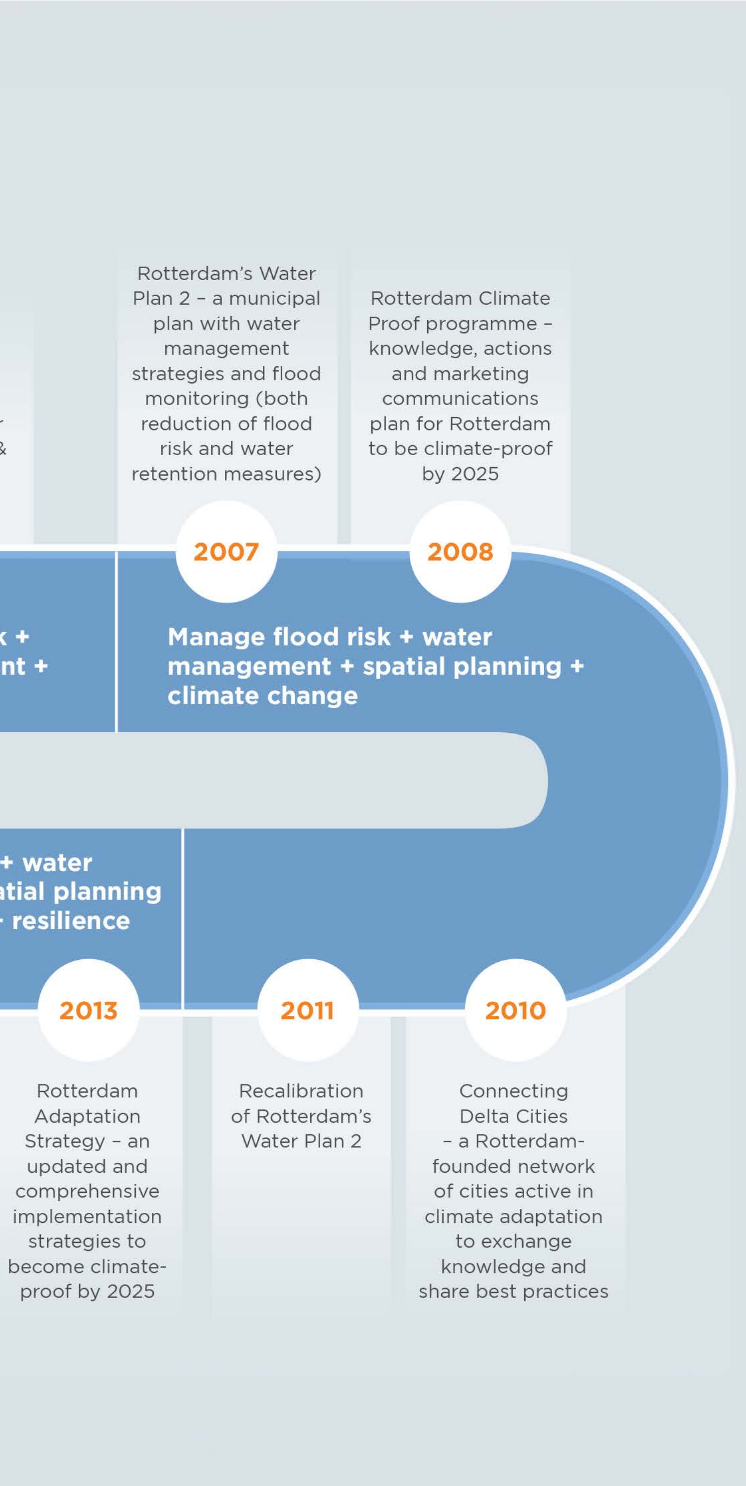
During World War II, Rotterdam suffered severe bombing, which devastated the city center and surrounding neighborhoods. During the city's reconstruction, water was pushed back out of the city to facilitate vehicle traffic. Many of the Singel Plan canals were turned into roads. The past resonates in current water management policies; with 85 per cent of the city below sea level and lacking surface water, urgent action is needed to address drainage inadequacies and keep the city dry during extreme precipitation events. Over the past two decades, Rotterdam has worked hard to adapt to climate change and to improve the city's water management, spa-



^ Fig. 2 The genesis of Rotterdam: historical parcellation pattern in relation to the current elevation map (Source: Municipality of Rotterdam, 2023).



^ Fig. 3 Timeline of water management policies in Rotterdam 2001–2020 (Source: Municipality of Rotterdam, 2019).



tial planning and resilience (fig. 3). Partly based on an extensive water system analysis, the Rotterdam water partners (municipal and the regional water authorities of Delfland, Schieland en de Krimpenerwaard and Hollandse Delta) formulated their joint vision in the first edition of Rotterdam's "Water Plan" in 2001. Themed "The Flood," the 2005 International Architecture Biennale Rotterdam became the starting point for a Rotterdam Water City 2035 vision. This resulted in "Water Plan 2: Working on Water for an Attractive City" (2007). In addition to addressing sustainable water management and adaptation to climate change, this Water Plan envisioned changing the spatial focus from a city scale to a metropolitan scale. With input from interest groups (e.g., social housing associations) and the engagement with local communities, the recalibration of "Water Plan 2: Water for an Attractive and Climate-Proof City" in 2011 integrates water management, urban planning and climate adaptation solutions. This third edition of Rotterdam's Water Plan comprises 13 sub-water plans in accordance with the city's urban typologies.

The Rotterdam Weather-Wise Plan (2019) and the Weather-Wise Program Framework 2030 (2023) complete the journey to date and can be considered the fourth edition of Rotterdam's Water Plan. To complement improvements to water safety infrastructure, water safety infrastructure, Rotterdam Weather-Wise aims to create a bottom-up movement to involve both public and private actors in implementing climate change adaptation measures. This transition from fighting water to living with water came about by necessity.

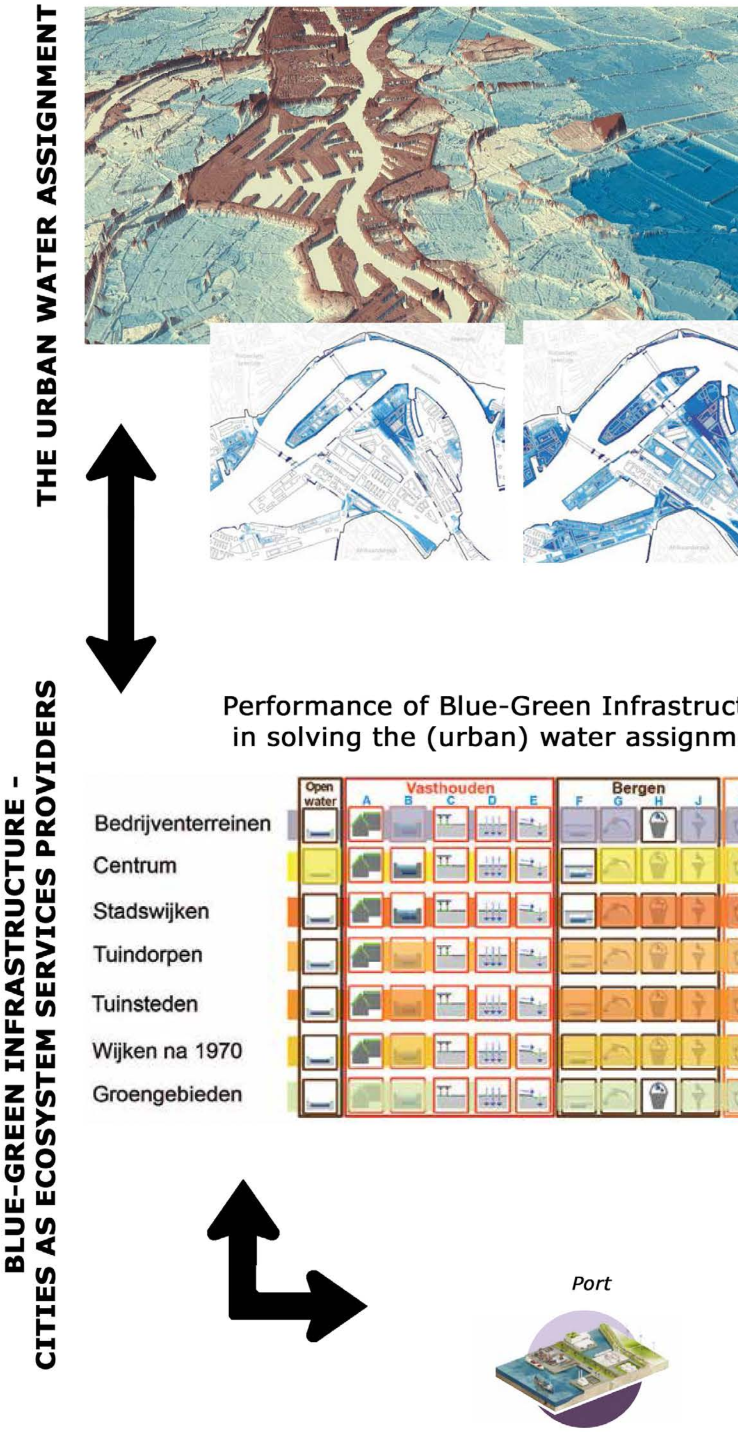
The current strategy is to adopt measures on a small scale that will increase the city's ability to absorb water ("city as a sponge") and, at the same time, improve outdoor public spaces. This strategy is increasingly visible in the city. Examples include several water squares (multifunctional, floodable public spaces) and alternative forms of water storage (e.g., underground water cisterns and urban water buffers), over 100 ha of green roofs and a rooftop park: an elevated park as a flood defense measure. Citizens' involvement contributed to the city's climate action efforts by turning paved areas into green spaces. In addition, the city council recently approved a plan to add seven major urban parks.

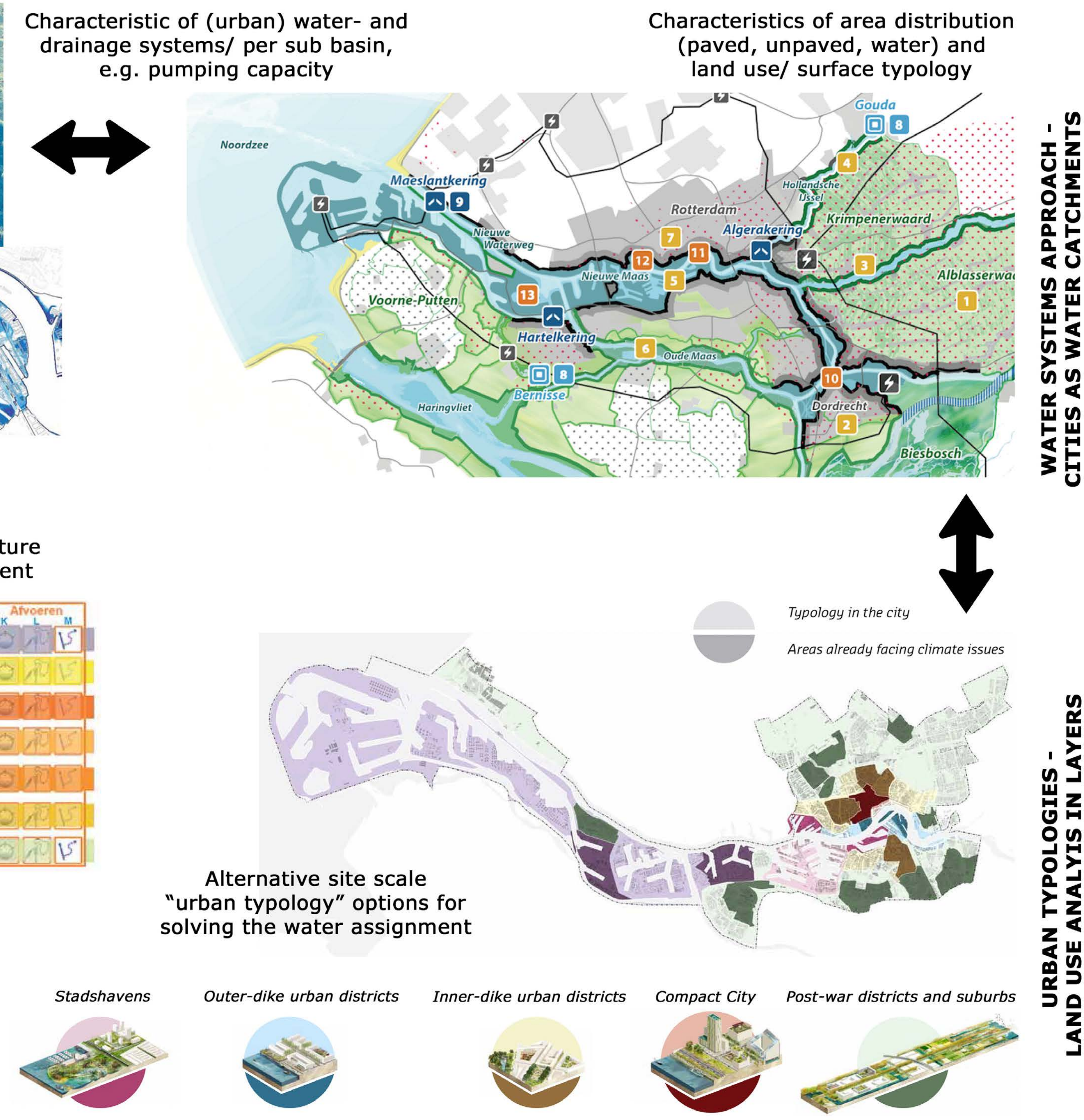
These parks aim to improve the quality of life and increase the attractiveness of the urban environment. Starting in 2024, a shift will be made from car-dominant paved areas to urban parks that will be accessible to pedestrians and cyclists, with a less dominant role for the car. The assumption is that people who live in places that are greener, cleaner and safer are healthier and happier.

The Present: Merging Blue-Green Infrastructure with Urban Design

Solving urban water problems in cities like Rotterdam requires a focus on the "Living with Water" principles of delay, store and drain (Ministry of Transport, Public Works and Water Management 2000). These principles represent a planning challenge for both water engineers and urban designers. Approaches in multifunctional infrastructure (rather than monofunctional or gray infrastructure) must be considered during the design process by linking the urban water problems to blue-green infrastructure metrics (e.g., system and site scale measures). Figure 4 distinguishes the following four quadrants (Dolman 2021):

1. Urban typologies – land use analysis in layers;





^ Fig. 4 Linking the urban water assignment (i.e., required water storage capacity) to blue-green infrastructure metrics, illustrated for Rotterdam (Source: Dolman, 2021).

2. Water systems approach – cities as water catchments;
3. The urban water assignment (i.e., required water storage capacity);
4. Blue-green infrastructure – cities as ecosystem service providers.

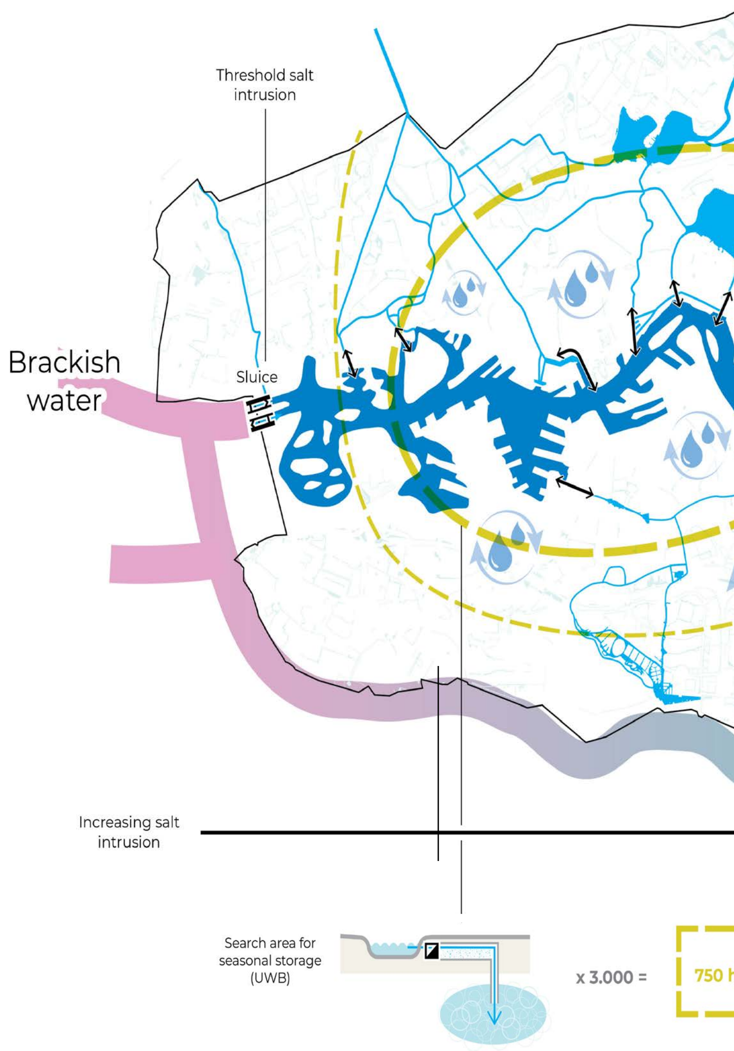
The design solutions to solve the urban water assignment are elaborated in Rotterdam's city planning and urban vision (statement) projects and demonstration (pilot) projects. Some practical measures and optional alternatives, both at system and site scales, include (re)use of water (rainwater harvesting, urban water buffers), surface drainage (delay), retention (water squares, streets, parks), infiltration (swales), green infrastructure, storage of surface water, and adaptive, flood-proof building and floating urbanism (Municipality of Rotterdam 2007).

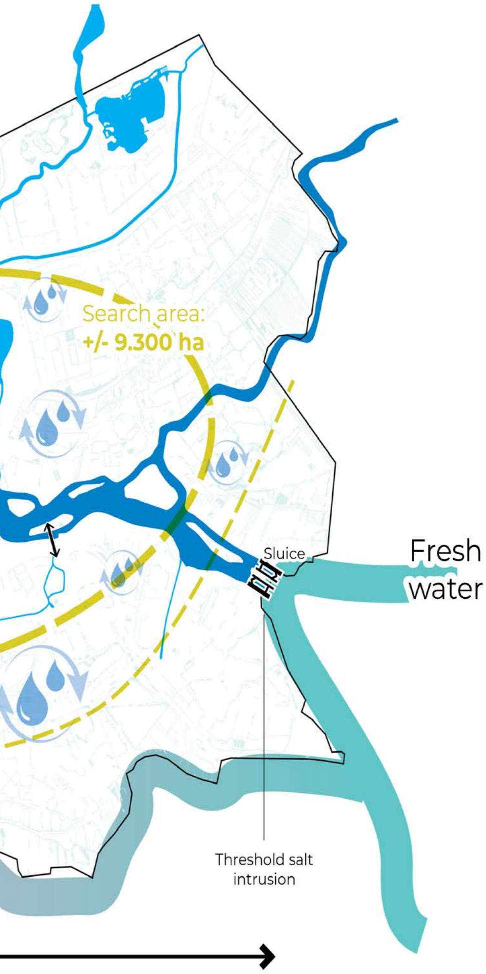
Rotterdam is transforming into a blue-green city by merging the Weather-Wise Program with the implementation of new green public spaces in seven iconic urban projects. Rotterdam has also moved away from working on projects "for" local communities and is instead focusing on projects "together with" local communities and is even supporting projects "by" local communities. The municipality of Rotterdam explicitly seeks cooperation with various stakeholders such as developers and property owners.

The Future: Rotterdam Water City 2100

Building on the Rotterdam Water City 2035 vision, the municipality of Rotterdam is currently exploring a hopeful vision of a blue-green sponge city of the future: Rotterdam Water City 2100 (De Urbanisten, LOLA and RHDHV, 2022), which is built on three pillars:

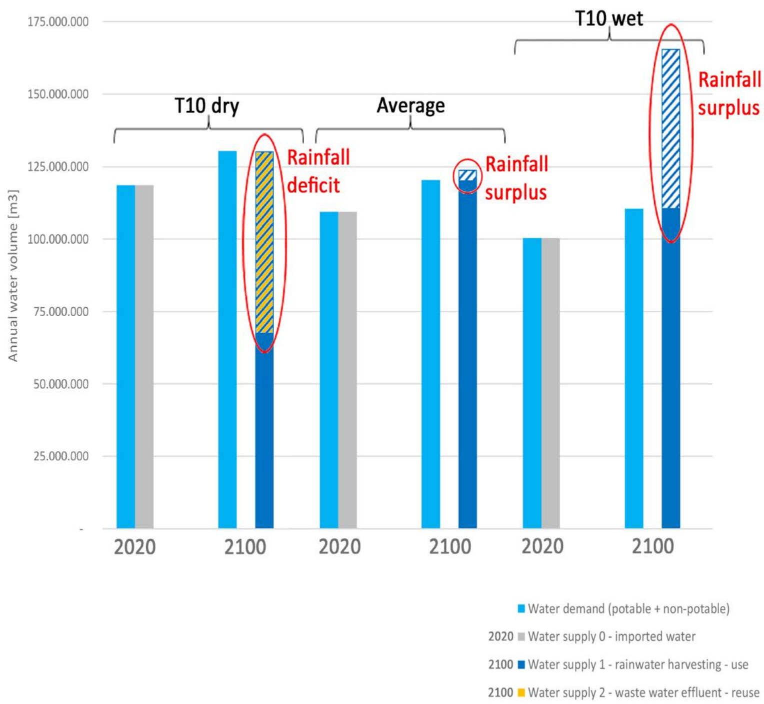
1. Flood protection: closing off Rotterdam from the open water;





One UWB holds 20,000 m3. With a depth of 10 m, an area of 2,500 m2 per UWB is required. For 3,000 UWB's this equals a total area of 750 hectares.

Supply (available) = Demand (required) *



Rotterdam Water City can supply its own water by optimal circulation. In a dry year approximately 60 million m3 of water is needed. This will require 3,000 urban water buffers (UWB's) under the city.

* Water balance calculations are based on an estimated total population of 1.1 million in 2100. In 2020 the area had 880,000 inhabitants - this includes Rotterdam, Schiedam, Barendrecht, Krimpen aan den IJssel and Capelle aan den IJssel.

^ Fig. 5 Water balance of Rotterdam Water City 2100 (Source: De Urbanisten, LOLA and RHDHV, 2022).

2. Flexible integration of land in water: wide, habitable, higher landscapes along the large waters;
3. Sponge City: blue-green infrastructure for long-term water resiliency and the security of the fresh water supply.

Considering the city a sponge is a strategy built on the "living water principles" of delay, store, drain only when necessary (Waggonner et al. 2014). This approach has been internationally recognized as a best practice through Tokyo's Water Saving City, Singapore's Closing the Water Loop and China's Sponge City Program (Dolman 2024). The aim of making Rotterdam a sponge city is to restore the water balance between urban areas and the surrounding environment. When it comes to optimal use of space, multifunctional water solutions and creating livable cities, the concept of "the city as a sponge" offers a way to address all water and climate challenges through water collection, storage and use. The city as a sponge contributes to the resilience of the landscape in which it lies, enhancing the quality of the living environment and promoting biodiversity.

In this vision, Rotterdam would take transformative measures, including implementing a delta dike protection system and becoming a self-sufficient, circular freshwater sponge city. With the New Meuse River as its central water body, enclosed by two double locks (fig. 5), the city would create a freshwater lake within its water system to facilitate further growth and utilization of this central water body. By closing off the New Meuse, additional housing opportunities would arise in former port areas outside the dikes, such as along canals and on houseboats. Commercial shipping routes currently heading toward the hinterland would be redirected further south. Moreover, waterfront areas would be enhanced with softer, greener designs, while an intelligent urban water system would function as a sponge, supporting the city's sustainability goals. The surrounding polders would be leveraged to more effectively withstand floods and droughts.

To be a sponge city, Rotterdam needs to absorb extreme storm events on all paved surfaces (by means of green polder roofs, wadis, rain gardens, water squares, soil improvement, storage under roads, etc.). The collected rainwater can also be buffered locally in the city using "urban water buffers." In dry periods, the water of these buffers in the aquifers is pumped up again and redistributed through the open water system to the entire city. This was tested in a conceptual water balance considering what 2100 would be like in a very dry year (serious shortage), in an average year (slight shortage), and in a very wet year (surplus). In an average and very wet situation, Rotterdam can supply its water demand with optimal circulation. The city is short 60 million m^3 of water in a dry year. This would be provided by storing the surplus in a wet year and then, in a dry year, transporting that back up into the city.

Conclusion

In the history of Rotterdam, water has mostly had a very positive influence on the city's development. The water that now poses severe threats, like flooding and drought, is the same water that has brought life and economic growth. Since the twentieth century, which was all about the fight against water and making way for the car, a radical change has taken place in water system thinking. By creating more space for water and promoting blue-green infrastructure in the built environment, Rotterdam is becoming climate-resilient, greener and more livable.

For Rotterdam to continue to be livable in 2100, the city must pursue a combination of protective measures and coping strategies. A key step is to create a closed freshwater cycle that allows Rotterdam to function as its own water supply catchment, working in harmony with a post-fossil port that has undergone a spatial, functional, and infrastructural transition. The aim is to restore the water balance between urban areas and their surrounding environment. By considering the optimal use of space and adopting multifunctional water and "livable city" solutions, Rotterdam can embrace the concept of "the city as a sponge." This approach involves the "collection, storage and use of water" to address all water and climate-related challenges (O'Donnell et al. 2021). Transforming Rotterdam into a Water City 2100 will contribute to the resilience of the landscape, enhancing the quality of the living environment and promoting biodiversity. By implementing these strategies, Rotterdam can continue to thrive safely and sustainably in the face of the challenges posed by climate change.

Policy Recommendations

- The transition toward a water-resilient Rotterdam shows the importance of a radical change in water system thinking, moving from the fight against water (past) to an approach of living with water (present).
- To keep Rotterdam safe and livable in 2100, it is crucial to work with nature. The recommended practices include (i) a good understanding of the urban water cycle and its itegration within urban planning strategies, (ii) a bottom-up movement to involve actors representing both public and private sectors, and (iii) implementing the right combination of gray and blue-green solutions.

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Nanco Dolman is the leading expert on water-resilient cities at Deltares, the Netherlands, and has wide experience in integrated (urban) water and spatial development projects. Nanco has worked on various water and adaptation strategies for delta cities in Thailand, the Netherlands, the United States, Bangladesh and China. From 2011 to 2016, he was a part-time lecturer in Water Management in Urban Areas at the Rotterdam University of Applied Sciences. He has also been involved in several international "blue-green cities" research studies as an applied researcher and field expert, such as with the EU Interreg NSR – CATCH project (2017–2022) and the British Academy-funded "Developing Blue-Green Futures" (2019–2021). Since 2021, Nanco has been participating in Redesigning Deltas (RDD), a research-by-design study that aims for a new Dutch condition in delta urbanism. One of the RDD designs is Rotterdam Sponge Water City 2100. Since 2020 Nanco has been a member of the editorial team of IWA's Journal of Water and Climate Change.

Contact: nanco.dolman@deltares.nl

Johan Verlinde is a climate adaptation and sustainability expert working as program director for Climate Adaptation at the City of Rotterdam. In his role as program director, Johan is responsible for overseeing the implementation of the "Rotterdam Weather-Wise" Climate Adaptation Plan. This plan aims to prepare the city for severe climate hazards, such as heavy rainfall, flooding, heatwaves and drought, by collaborating with citizens, the private sector, social housing corporations, water boards and citizens. Johan's expertise lies in devising innovative climate-adaptive measures in public spaces, where space is scarce. He recognizes the importance of climate-proofing private spaces, which will become increasingly critical in the future. Johan is participating in several international collaborations, including C40 Cities, where he shares and gains knowledge on climate adaptation. He was a PUB Singapore Water Academy fellow from 2019 to 2021.

Contact: j.verlinde@rotterdam.nl