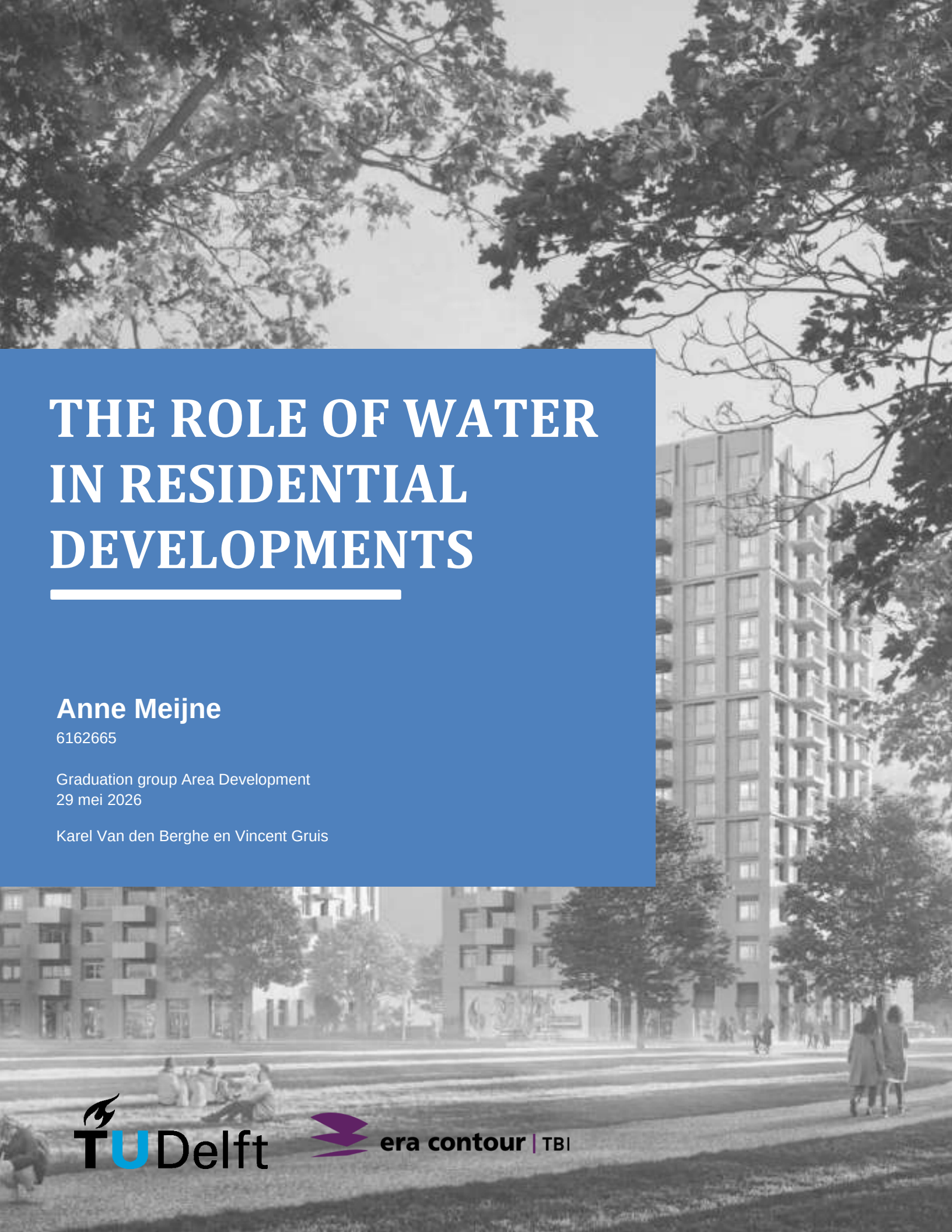

THE ROLE OF WATER IN RESIDENTIAL DEVELOPMENTS

Anne Meijne
6162665

Graduation group Area Development
29 mei 2026

Karel Van den Berghe en Vincent Gruis

TU Delft

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Preface

My motivation for choosing this thesis topic grew from an interest in circular themes within the built environment together with a good conversation and the increasing relevance of water in construction. Circular water use was unfamiliar at first, yet the early conversations immediately drew me in and it felt like a topic that deserved more attention. The chance to examine this topic in depth during my master's programme made the research both timely and significant. As my thesis progressed, the rising number of reports on water scarcity and the construction sector's role highlighted its growing societal relevance.

Although I had completed research during my HBO studies, this project required a different level of depth and reflection. Working on a topic that is still developing within the construction sector brought challenges: limited information, shifting focus of importance and moments where progress felt uncertain. These experiences forced me to sharpen the problem definition, question assumptions and look beyond standard approaches. My background in the built environment, combined with practical experience from earlier studies and internships, helped me approach this topic from both a technical and organisational perspective. This thesis aims to contribute to a field where knowledge is still emerging by offering insights that can support both academic discussion and practical decision-making in residential high-rise development.

I would like to thank my first supervisor, Karel van den Berghe, for his critical guidance and contagious enthusiasm for exploring circularity through the lens of water. Even during a busy period in his personal life, he continued to challenge my thinking and keep the research focused. My second supervisor, Vincent Gruis, was someone I always left with new ideas after our discussions, clearer direction, and renewed motivation. His way of reading between the lines and asking the right questions helped me find my own path through the research, a form of guidance I am extremely grateful for.

I am also grateful to everyone at ERA Contour and in particular my supervisors Benno van Dam and Thobias Thoen whose practical perspective grounded this research. Their willingness to brainstorm, connect me with experts and explore this relatively new topic together made the project more relevant and applicable. Their interest in using the findings in practice added real value to the work and inspired me. Lastly, I would like to acknowledge the people around me for their continuous support throughout this process and to believe in me. Their encouragement has been valuable and is appreciated more than they may realise.

The combination of academic and practical guidance reflects the interdisciplinary nature of this thesis and that of water. Different perspectives came together and helped shape the final result. I hope you enjoy reading this thesis and that its findings offer a useful contribution to the ongoing discussion about water, circularity and the future of residential development.

Anne Meijne

Mei 2026

Abstract

Water is a critical but undervalued resource, with buildings and construction accounting for approximately 15% of global freshwater withdrawals (Montano-Owen & Brady, 2023). While Circular Economy (CE) strategies in construction increasingly target carbon reduction and material reuse, water use, both operational and virtual, remains insufficiently addressed (Rashid et al., 2025).This research examines the role of water in high-rise residential development by analysing the quantity, timing, and impact of water during material production (virtual water) and building operation, and investigates the drivers, barriers, and practical opportunities for implementing circular water-saving solutions.

A combination of quantitative and qualitative strategies was used for the research. Virtual water impacts were calculated using an Economic Input-Output Life Cycle Assessment (EIOLCA) and Environmental Product Declarations (EPDs), organised through the Quantity-Time-Impact (Q-T-I) framework and applied to a Dutch high-rise case study. Water use and implementation dynamics were examined through semi-structured interviews.

The findings show that water use in high-rise development is both large and largely invisible. Embodied water in construction materials, particularly concrete and aluminium, equals roughly 29 years of operational water use, meaning nearly one-third of the total lifecycle water demand is already fixed before the first resident moves in. Material choices and procurement decisions made early in the design phase therefore determine this footprint in ways that cannot be corrected later. Operational water use accounts for the remaining two-thirds over a 75-year lifespan and offers the largest direct reduction potential: 30-50% through efficient fixtures alone, and up to 70% when combining greywater and rainwater reuse.

Implementation of these solutions is shaped by five interconnected factors: low awareness and knowledge of water footprints, municipal requirements (increasingly acting as a driver, as in The Hague), financial feasibility constraints (greywater reuse systems carry payback periods of up to 60 years under current water prices), regulatory barriers limiting indoor use of rainwater and treated greywater, and execution and maintenance complexity in high-rise settings. Despite these barriers, developing contractors hold a central coordinating position that allows them to influence procurement, early design, and stakeholder collaboration. By applying a small-wins approach, preparing buildings for future greywater reuse, integrating water-impact optimization in early design phases, or initiating supplier conversations, contractors can trigger broader organisational change and lower barriers for more comprehensive circular water strategies.

This research advances the Circular Water Economy (CWE) by linking lifecycle water assessments with organisational decision-making. It provides developers and contractors with actionable guidance to reduce water footprints beyond regulatory compliance and demonstrates that integrating circular water principles into project execution is both feasible and increasingly necessary under growing water scarcity and tightening regulations.

Keywords Circular Water Economy (CWE), Virtual Water, Residential Development, Life Cycle Assessment (LCA), Circular Construction and operational water, Drivers and barriers

Keywords

Black water = is highly contaminated water that contains a mixture of feces, urine, and flushing water, with high concentration of organic matter (Xu et al., 2023).

Blue water = Includes surface and groundwater stored in rivers, lakes, reservoirs and aquifers (Mekonnen & Hoekstra, 2016). It is the primary source of potable water.

Brakish water = ''Brackish water is a broad term used to describe water that is more saline than freshwater but less saline than true marine environments. Often these are transitional areas between fresh and marine waters.'' (Gray. S et al., 2011)

Circular economy = as a society 'where the consumption of natural resources is reduced and the environmental load is minimised to the fullest extent possible'(Arai et al., 2024)

Green water = refers to soil moisture used by plants and microorganisms and returned to the atmosphere through evapotranspiration (Mekonnen & Hoekstra, 2016). While essential in agriculture, it plays a limited role in construction processes.

Grey literature = information that is published outside the traditional commercial or academic publishers. Examples are research reports, policy nota or newsletters.

Grey water = previously used water containing impurities and typically treated before discharge. In water-footprint accounting, it also represents the volume required to dilute pollutants to acceptable levels (NEN-EN-ISO 14046;2016, 2016; Ghaly et al., 2021)

Peat dikes = (Veendijk) are historic defences for flood prevention and water barriers. Common in the Netherlands, constructed from organic peat soil or layers of peat and clay (Strijker et al., 2024)

Virtual water = the indirect water used throughout the life cycle of a building, including material production, construction activities, energy generation and the goods and services consumed by occupants (Crawford & Pullen, 2011).

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1. Introduction

Water is a limited and essential resource, with less than 1% of the Earth's freshwater suitable for human use (Montano-Owen & Brady, 2023). Yet water is often treated as a low value resource, resulting in inefficient use, pollution and waste because its true value is insufficiently reflected in economic and decision-making processes (Conner, 2021). The built environment contributes significantly to this challenge: buildings and their construction account for an estimated 15% of the global freshwater withdrawals (Montano-Owen & Brady (2023). Life-cycle studies further show that water use extends far beyond direct consumption. Crawford & Pullen (2011) for example, demonstrated that a residential building's indirect water use, embedded in materials, construction processes and goods consumed over 50 years, represents a substantial share of its total water footprint. If current consumption patterns continue, half of the global population may face water scarcity by 2050, emphasizing the urgency of rethinking water use in the built environment.

The Netherlands is not exempt from these global pressure. Projections by the RIVM indicate a shortage of 100 billion litters of potable water by 2030, driven by population growth, limited groundwater extractions, industrial demand and climate-induced droughts (Van Leerdam et al., 2023). This emerging scarcity directly affects urban and residential development, where both construction processes and household use rely heavily on high-quality freshwater.

Climate change, rapid urbanization and limited groundwater extractions result in an increase of water resource scarcity and is intensifying pressure on urban water systems. Rockström et al. (2009) show that several planetary boundaries have already exceeded and that freshwater may soon be approaching. At the same time, water demand continues due to both household consumption and the water-intensive nature of construction. Despite these pressures, urban expansion has not slowed down. The Netherlands faces a housing shortage of approximately 400,000 dwellings (Hopman et al., 2019), meaning that new construction will further increase water demand during both the building process and the operational phase. As a result, residential development is becoming an increasingly important contributor to the stress on water systems that are already nearing their ecological limits.

In response to growing environmental pressures, circular economy (CE) principles are increasingly promoted as an alternative to linear resource use. While CE has been described in many ways, Kirchherr et al. (2017) identify more than 100 definitions, the Japanese interpretation offers a particularly relevant perspective for this research regarding CE with water. Arai et al. (2024) define CE as a societal system in which the consumption of natural resources is reduced and environmental burdens are minimised as much as possible. This interpretation applied to water, emphasises resource efficiency and the reduction of environmental load. Circular water economy CWE, aims to minimise freshwater extraction while maximising reuse, recycling, infiltration (Morseletto et al., 2022; Nika et al., 2022). Circular water strategies therefore provide a promising approach for addressing the increasing mismatch between water demand and availability in residential development.

The research is structured by first examining the broader context of water scarcity and then narrowing the focus to the role of water in high-rise residential buildings. High-rise is selected because it is an increasingly dominant typology in Dutch urban development and presents unique spatial and technical constraints for implementing (circular) water-saving solutions. Within this scope, the analysis concentrates on the material production phase (A1–A3) and the operational phase (B1 and B7), while acknowledging that other life-cycle stages also influence water use. The primary materials assessed are aluminium, concrete and brick, selected because they are either highly water-intensive or widely used in construction. Water use during material production far exceeds on-site consumption, and therefore on-site construction water is not included in the assessment. The study focuses on solutions that fall within the influence of developing contractors, recognising that their leverage is limited in material production but more substantial in project execution and operational strategies. Due to time constraints, only a shortlist of feasible solutions is analysed in depth.

1.1 Problem statement & goal

Water scarcity is becoming an increasingly urgent issue in the built environment, including in The Netherlands, where drought and declining potable water availability are no longer limited to higher-lying regions. Despite this growing pressure, water use in residential development remains poorly understood before the operational phase (Morseletto et al., 2022, Nika et al., 2022). Evidence from Belgium demonstrates however that during the operational phase substantial reductions in potable water use, up to 35%, can already be achieved (Bich-Ngoc et al., 2022). This illustrates both the urgency and the potential for reducing potable water demand for housing in both material production and the operational phase.

However, current Circular Economy (CE) strategies in construction primarily focus on carbon reduction and material reuse, while water receives comparatively little attention (Rashid et al.,2025), despite its importance across nearly all Sustainable Development Goals (United Nations, 2018).

The connection between water use in material production and operational water use within CE frameworks remains underexplored, particularly for high-rise residential buildings. High-rise developments are increasingly common due to urban densification, land scarcity and demographic change (Al-Kodmany, 2022; Abbood et al., 2021).Yet, these buildings face technical and spatial constraints that complicate the implementation of (circular) water-saving solution, making them a relevant and challenging context for analysis.

The goal of this research is to clarify the role of water in high-rise residential developments by analysing its quantity, timing and impact during material production and the operational phase. In addition, the study identifies the drivers and barriers that influence the implementation of (circular) water-saving solutions. Together, these insights aim to support developers and contractors in reducing water use within their projects and in integrating circular water principles into project execution.

1.2 Scientific and societal relevance of the research

Scientifically, this research positions water as a central resource within CE practices by analysing its role across quantity, time and impact in high-rise residential development. It contributes to the limited body of knowledge that connects virtual water in material production with operational water use, and integrates these insights for project implementation. By examining the drivers and barriers to implementing circular water-saving solutions, the study brings together multiple perspectives that are often treated separately in existing literature.

Societally, the research supports more sustainable and resilient housing development by providing developers and contractors with practical insights into how (circular) water principles can be operationalised within project execution. By clarifying the influence and responsibilities of developing contractors, the study encourages earlier integration of water considerations in the development process, contributing to broader CE ambitions and long-term water security.

1.3 Research questions

For this research the main research question is:

> ***What is the role of water in residential high-rise buildings during material production and the operational phase and how can developing contractors operationalise (circular) water-saving solutions into their projects?***

To answer the main question the sub-questions are:

1. What is the role of water in terms of quantity, time and impact for the material production and the operational phase for residential high-rise buildings?
2. What is the reason that some (circular) water-saving solutions are being implemented nowadays and some are not?
3. Which (circular) water-saving solution can developing contractors implement within their projects?

2. Literature study

Water plays a critical role in both material production and building operation, yet its use is often overlooked compared to energy or carbon. To address this gap, this literature study examines where water pressure arise and why these issues are increasingly urgent for the construction sector. It also explores how the role of water can be assessed an clarifies the principles of water within the Circular Economy, and how these frameworks shape strategies for reducing freshwater demand. Because water operates across multiple spatial scales and life-cycle phases, the review also discusses how these scales interact and why they matter for understanding impacts.

Together, these insights form the analytical lens used in the results chapter to determine how much, when and where water plays a role in residential high-rise development to later look into the drivers and barriers to identify feasible (circular) water-saving solutions into the projects.

2.1 The water challenge

2.1.1. Water scarcity and excess

The Netherlands faces three water quantity challenges: **water scarcity**, **water excess** and **potable water** all three intensified by climate change.

WATER SCARCITY

Water scarcity has increased due to longer droughts, limited groundwater extraction and rising households demand. In 2022, the Dutch government declared a *"de facto water shortage (level 2)"* as drought conditions worsened, reflecting a broader European trend of severe drought (Toreti et al., 2025).

Although national annual water availability is sufficient, the Beleidsnota Drinkwater 2021-2026 shows that regional and seasonal shortages already occur, particularly in Overijssel, Gelderland, Zuid-Holland and Groningen, where water utilities report a negative operational reserve (Ministerie van Infrastructuur en Waterstaat, 2021). Groundwater supplies around 60% of this potable dutch potable water, while the western provinces depending more heavily on the Maas and Rhine. The Rhine is currently less affected by low flows due to snowmelt and upstream basin contributions (Toreti et al., 2025).

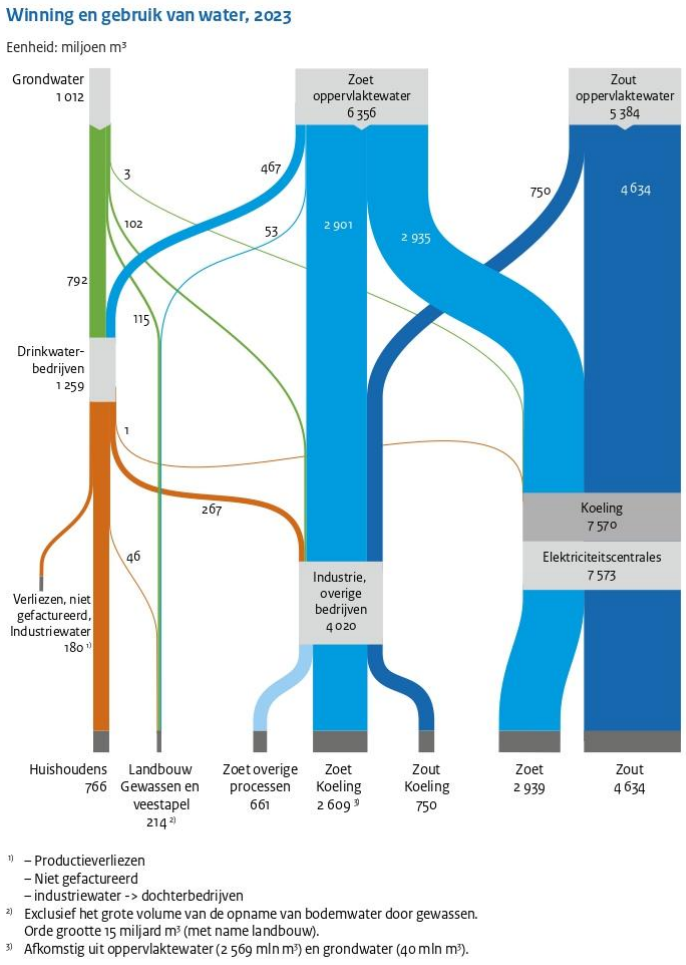

Figure 1 - Water origin and use in Netherlands 2023 by CBS (https://www.clo.nl/indicatoren/nl005718-waterwinning-en-watergebruik-in-nederland-1976-2023)

A complete overview of Dutch water use is provided by the Compendium voor de Leefomgeving (CLO), which documents national water extraction and consumption trends from 1976 to 2023 is shown in Figure 1 (CLO, 2026). This dataset shows that households rely predominantly on groundwater for their potable water supply, making blue and grey water the most relevant categories for analysing water use in this research. Because this study focuses on water use during material production and the operational phase, the emphasis is placed on these water types rather than on agricultural or surface-water dynamics.

POTABLE WATER

Household potable water use has remained stable for the last three decades, averaging 128 liters per person per day (LPPPD) (Van Leerdam et al., 2023; CLO, 2026). The government aims to reduce this to 100 LPPPD by 2035 to comply with the rising households (Harbers & Heijnen, 2022).

Looking ahead, water utilities expect structural bottlenecks before 2030, particularly in the areas of Twente, Utrecht–Amersfoort, the Veluwe and Rivierenland. Supplying 100.000 new homes requires roughly 10 million m^3 of additional annual production and permit capacity, levels many regions cannot yet guarantee (Ministerie van Infrastructuur en Waterstaat, 2021). Increasing droughts frequency further threatens long-term supply reliability (Van Leerdam et al., 2023; Spinoni et al., 2017)

EXCESSIVE WATER

At the same time, the Netherlands also faces periods with excessive water. Climate change leads to heavier rainfall, more extreme river flows, stronger storms and rising sea levels. For this research, heavy rainfall events are particularly relevant, as they require adequate infiltration capacity in the built environment. Increasingly intense rainfall can overwhelm drainage systems and cause local flooding (Van Dorland et al., 2024).

Together, these developments show that potable water availability is becoming a critical constraint for future housing development. Dense urban environments, more households, more droughts and rising water demand threaten potable water supplies, while extreme rainfall overwhelms drainage systems. This dual challenge reinforces the need for more efficient and circular water use in residential projects.

2.1.2. Urgency for the construction sector

Water scarcity and excess are no longer abstract environmental concerns but increasingly direct constraints on Dutch construction sector. The sector is expected to contribute to reducing potable water demand and improving rainwater infiltration in response to heavier rainfall events.

As outlined above, the combined challenges of water scarcity, water excess and emerging potable water shortages mean that long-term supply reliability can no longer be guaranteed (Van Leerdam et al., 2023). This has immediate consequences for the building sector; without structural reductions in potable water demand, it will be impossible to supply all 900,000 planned new homes with a potable water connection (Drinkwaterplatform, 2025). Water availability will therefore becoming an execution bottleneck, comparable to the nitrogen crisis or grid congestion.

Regulatory pressure further increases this urgency. The Netherlands is expected to miss its 2027 targets for the EU Water Framework Directive (WFD), which may lead to fines and stricter permitting conditions (European Commission, 2000). From 2028 onward, this could result in restrictions on dewatering, additional testing, delays in environmental permits and higher project risks. A study by Witteveen+Bos estimates that these constraints could cause up to €17.5 billion in construction losses in a worst-case scenario. (Phernambucq et al., 2023).

In response, the sector is increasingly expected to contribute to adopt water-efficient building principles. Proposed regulatory measures include integrating water-saving requirements into the Bouwbesluit and Drinkwaterbesluit, which are active topics in governmental discussion in 2026 (Vewin, 2026). Circular water-saving solutions, such as greywater reuse, rainwater buffering and low-water materials, offer potential for reducing potable water use during both construction and in the operation (Morseletto et al., 2022). These developments create both obligations and opportunities: companies that adopt circular water solutions within their projects can reduce risks for the residents and society while strengthening their negotiation position in area development.

In summary, water scarcity, regulatory tightening and slowly rising sustainability goals make water a strategic issue for developers and contractors. Addressing water use across the building life cycle is becoming essential for safeguarding construction continuity and enabling sustainable urban growth.

2.2 Understanding water use in buildings

2.2.1. Water consumption assessment of buildings

Understanding water use in the built environment requires distinguishing between two fundamental categories of water demand: operational water consumption and virtual water consumption. Together, these categories capture both the visible and invisible water flows associated with buildings across their life cycle.

OPERATIONAL WATER CONSUMPTION

Operational water consumption refers to the direct use of water by occupants for sanitation, hygiene, and household activities, and is influenced by behavioral, technical and soci-economic factors (Heravi & Abdolvand, 2019). Although operational water use is significant, it can be substantially reduced through technological and behavioural interventions. Efficient fixtures can lower demand by up to 50%, while greywater and rainwater reuse systems can achieve reductions of up to 70% (Amado & Barroso, 2013). Because these measures fall within the influence of contractors and building developers, operational water consumption remains a key area for practical improvement.

VIRTUAL WATER CONSUMPTION

Virtual water consumption encompasses the indirect water used throughout the building life cycle, including material production, construction activities, energy generation and the goods and services consumed by occupants. This concept, rooted in the water footprint framework, highlights the substantial volume of “invisible” water embedded in supply chains (Crawford & Pullen, 2011).

Virtual water has been assessed in several national contexts, including Australia (McCormack et al., 2007; Crawford & Pullen, 2011), China (Han et al., 2016), Iran (Heravi & Abdolvand, 2019) and India (Bardhan, 2011). These studies demonstrate that virtual water levels vary widely depending on construction standards, building methods and material, climate, water availability and societal attitudes toward water use. This variation underscores the need for country-specific assessments to support informed policy and management decisions for implementation.

EVIDENCE IN STUDIES

Crawford & Pullen (2011) conducted a 50-year life-cycle water analysis of a typical Australian low-rise residential building. Their results showed that direct household water use accounted for only 6.4% of total water demand. Indirect water embodied in construction, maintenance and refurbishment materials contributed 9.7%, while consumables, particularly food, represented 46%. Additional significant contributors included building materials, vehicle production and electricity generation also contributed significantly. Although buildings are often cited as responsible for around 12% of global direct water consumption, their indirect contribution is far greater when virtual water is included.

In Iran, Heravi & Abdolvand (2019) found an average virtual water consumption of 20.8 m^3 per m^2 of floor area in residential projects, with steel production alone responsible for 58% of total water use during the realisation of the project.

Similarly, Han et al. (2016) reported that virtual water consumption in a commercial building project in Beijing was nearly 24 times higher than during on-site construction. Materials such as steel, cement, lime and metal products accounted for more than 75% of the total water footprint.

IMPLICATIONS FOR BUILDING ASSESSMENT

Collectively, these studies highlight the necessity of integrating both direct and indirect water flows when evaluating building-related water consumption. Water impact occurs at different life-cycle stages, at different scales and through different types of water. As a result, assessing water use requires more than measuring volumes alone. A structured framework is needed that connects quantity, timing and impact across both material and operational phases of a building's life cycle.

2.2.2. Circular (water) economy defined

Circular economy (CE) principles are receiving increasing attention as cities grow and climate change intensifies. The concept originated in the 1970s (Arai et al., 2024) and now encompasses more than 100 definitions (Kirchherr et al., 2017). The Japanese interpretation defines CE as a society 'where the consumption of natural resources is reduced and the environmental load is minimised to the fullest extent possible' (Arai et al., 2024). This perspective emphasises resource efficiency and environmental impact reduction rather than solely closing material loops.

The circular water economy (CWE) builds onto these circular economy principles by reducing the consumption of natural water resources and minimising environmental impacts. Rather than relying on linear "take–use–dispose" models, CWE emphasizes closing water loops through avoidance, reduction, reuse, recycling and renewal. According to the ELLEN MACARTHUR FOUNDATION (2021), CWE seeks to minimise unnecessary water use, reduce demand through efficiency, reuse water within and across systems, and replenish water bodies at the basin scale.

Riazi et al. (2023) highlight that successful implementation of CWE depends on more than technological solutions. Their analysis of case studies in Spain, Italy, Croatia and Israel shows that water reuse introduces new water types, risks and actor relationships, thereby challenging existing governance structures. As water systems become more circular, institutional complexity increases, particularly in relation to quality standards, responsibilities and conflict prevention.

At the urban and district scale, Tucci et al. (2024) extend the CWE concept by integrating architectural and spatial design strategies. Their framework for climate-proof urban districts combines water diversion, reception and source control to manage both water scarcity and excess. By assessing green-blue and grey infrastructures through key performance indicators, the study demonstrates how circular water strategies can enhance flood regulation, water quality and urban biodiversity.

2.3 Concepts and analytical framework

2.3.1. Types of water

Water used during material production and in the operational phase is commonly categorized into blue, green and grey water. Categories widely applied in water-footprint and (Hoekstra & Chapagain, 2007; Mekonnen & Hoekstra, 2016). Virtual water assessments focus primarily on blue and green water quantity, while water-footprint assessment also considers grey water (Ridoutt & Pfister, 2013). This distinction is important because different water types have different environmental implications and levels of scarcity.

Blue water includes surface and groundwater stored in rivers (Mekonnen & Hoekstra, 2016). It is the primary source of potable water and is heavily relied upon in the Dutch context for households and industry, even for low-grade uses such as toilet flushing. Sometimes blue water is referred to as freshwater or ''zoetwater'' in Dutch and is used for human consumption. Then you have brackish water within transitional areas between fresh and saltwater or marine waters.

Green water refers to soil moisture used by plants and microorganisms and returned to the atmosphere through evapotranspiration (Mekonnen & Hoekstra, 2016). While essential in agriculture, it plays a limited role in construction processes. Grey water is previously used water containing impurities and typically treated before discharge (Ghaly et al., 2021). Lastly black water, consisting of wastewater contaminated which is highly contaminated by feces, urine, and flushing water, is highly polluted (Xu et al., 2023). The distinction between water types also shows that water impacts cannot be captured by a single metric. It is interconnected and is dependent on the place the water is used.

Environmental Product Declarations (EPDs) report water use using word equivalent deprived (WDP) indicator, based on the AWARE method. This method adjusts water use by its scarcity (Serafini & Ciroth, 2024; Boulay et al., 2018). This ensures that water use in water-stressed regions is weighted more heavily than in water-abundant areas.

2.3.2. Phases

Time is one of the three indicators in the multi-dimensional framework. To analyze the temporal dimension of water use, this research uses the stages of the EPD based on EN 15804 (NEN, 2019) , which provide insights into the life-cycle phases of materials. EPDs phases as shown in Figure 2distinguish the production stage (A1–A3), construction stage (A4–A5), use stage (B1–B7), end-of-life stage (C1–C4) and recovery stage (D).

For this research, the primary focus is on modules A1–A3 for material production and modules B1 and B7 for the operational phase. Other phases are considered but not central to the analysis. Excluding them entirely would give an incomplete picture, for example, concrete may require water during demolition or recycling.

Modules declared, geographical scope, share of specific data (in GWP-GHG results) and data variation (in GWP-GHG results):

	Product stage			Construction process stage		Use stage							End of life stage				Resource recovery stage
	Raw material supply	Transport	Manufacturing	Transport	Construction installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
Module	**A1**	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
Modules declared	X	X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	X	X	X	X	X
Geography	GER	GER	GER	GER	-	-	-	-	-	-	-	-	GER	GER	GER	GER	GER
Specific data used	67%			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Variation – products	0%			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Variation – sites	0%			-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 2 - EPD levels (EPD urban mine)

2.3.3. Scales

Water flows across multiple spatial scales, each scale with different challenges and implications for high-rise residential development. As (Tjallinghii, 1996) argues, water flows, areas, and actors are always interconnected, meaning that decisions at the building level influence district systems, and district decisions influence city & regional water bodies. The Dutch ''Menukaart water'' similarly divides solutions into household, collective and neighborhood levels, illustrating that effective water management requires action at multiple scales simultaneously. For this research a distinction of the scales is pictured in Figure 3 and will be highlighted per scale.

BUILDING

At the building scale, water is used directly for daily activities (showering, toilet flushing, appliances) and indirectly through consumer goods, embedded within materials and for construction. Building-level solutions can significantly reduce potable-water demand, but they cannot solve larger hydrological problems alone (Amado & Barroso, 2013). Outside the building, water also interacts with the surrounding terrain through processes such as infiltration, wadi's, drainage, and buffering on roofs or in small retention systems.

DISTRICT

At the district scale, water interacts with shared systems such as sewer networks, green spaces, infiltration zones, and local surface water. District-level strategies such as collective rainwater systems, wadi's green-blue infrastructure (Tucci et al., 2024).

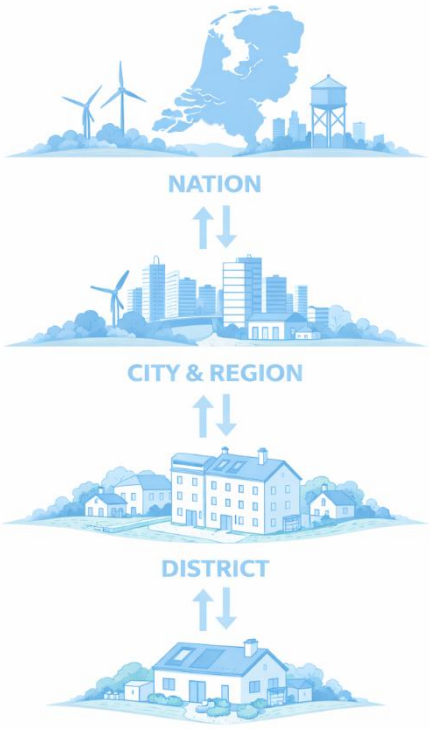

Figure 3 - Scales within the built environment for this research (own image)

CITY AND REGIONAL

At the city and regional scale, water systems include canals, rivers, groundwater bodies, and drinking-water extraction areas. These systems determine the potable water availability and drought severity.

NATIONAL

At the national scale, water policy, regulations and long-term planning determine how water scarcity and excess are managed. The EU Water Framework Directive (WFD) and Dutch potable water policies influence construction permits, dewatering rules, and the availability of potable water for (new) housing developments (European Commission, 2000). National shortages or regulatory tightening can directly delay or restrict building projects.

In short, water impacts residential development from the smallest scale (the building) to the largest (the national water system). Effective solutions must therefore be looked at on a multi-level, combining building-level efficiency with neighborhood infrastructure and regional or national water management.

2.3.4. Multi-dimensional frameworks

The literature study shows that water use in buildings is multi-layered: it involves different water types, occurs across multiple life-cycle phases, and is influenced by decisions at building, neighbourhood, regional and national scales. Existing studies highlight that operational water use alone provides an incomplete picture and that virtual water in material production can be equally or more significant.

To analyse these interconnected dimensions in a structured way, this research uses a multi-dimensional framework combined with an Economic input-output life cycle assessment (EIOCLA) to understand the role of water in the material production and during the operational phase of residential area development projects.

The aim is to look at water use not only in terms of numbers, but to connect them in relation to when, where and how water is relevant during the case project. The multi-dimensional approach combines technical data for analysing virtual water with organisational and process insights.

For the analysis of virtual water usage a lot of different techniques can be classified broadly into three separate groups: process analysis, input–output (I-O) analysis and hybrid analysis (Bullard et al., 1978; Suh et al., 2004). For this research, an Economic Input-Output Life Cycle Assessment (EIOLCA) is used. EIOLCA uses average sector data to estimate water use when detailed product-level data is unavailable, particularly relevant because water is an emerging topic in the sector and data availability is limited. Although EIOLCA is not precise at product level, it is useful for identifying overall water impacts and major water-intensive materials.

To structure the analysis, the Quantity, Time and Impact framework is applied. This Q-T-I framework helps to assess:

- How much water is used
- When and for how long water is relevant during material production and operational use
- Where the impacts occur within the project area and its supply chain.

By combining life-cycle water data with a structured framework, this research supports developers in understanding the role of water and making practical decisions on (circular) water-saving solutions for their projects.

2.4 Knowledge gap

The literature shows that substantial body of research exist on water us in construction project, both for operational water use and for virtual water use in material production. However, important gaps remain.

First, water consumption studies often remain fragmented, focusing either on operational use (Amado & Barroso (2013) or on virtual water (McCormack et al., 2007;Crawford & Pullen, 2011;Han et al., 2016; Heravi & Abdolvand, 2019; Bardhan, 2011) with limited integrating of these dimensions into a unified assessment framework. Second, while CWE principles are well described at a conceptual and policy level (Tucci et al., 2024), their translation into enforceable project implementation remains limited (Riazi et al., 2023; Sakhardande et al., 2025).

Third, organisational and operational perspectives, particularly for the material production phase, are underrepresented in CWE research, despite their significant influence on water consumption patterns.

Overall, there is a need for research that connects life-cycle water assessment with (circular) water-saving solution using a multi-dimensional framework. By linking water use to different levels and scales, material production, construction and building operations, this research helps clarify how much water is involved, when it matters, what enables or hinders solutions and where impact occur.

2.5 Conceptual model

The conceptual model shown in Figure 4, how the main concepts of this research are connected through a chain of cause and effect. It shows how the role of water in residential high-rise development is shaped, and how (circular) water-saving interventions can influence this process. The starting point is a new project development, which directly increases both virtual water (embedded in material production) and operational water (household consumption during use).

Together, these two streams raise the total water demand. Higher water demand leads to greater water scarcity, particularly in regions already under pressure. This creates a clear chain: project development → higher virtual & operational water → higher water demand → increased water scarcity

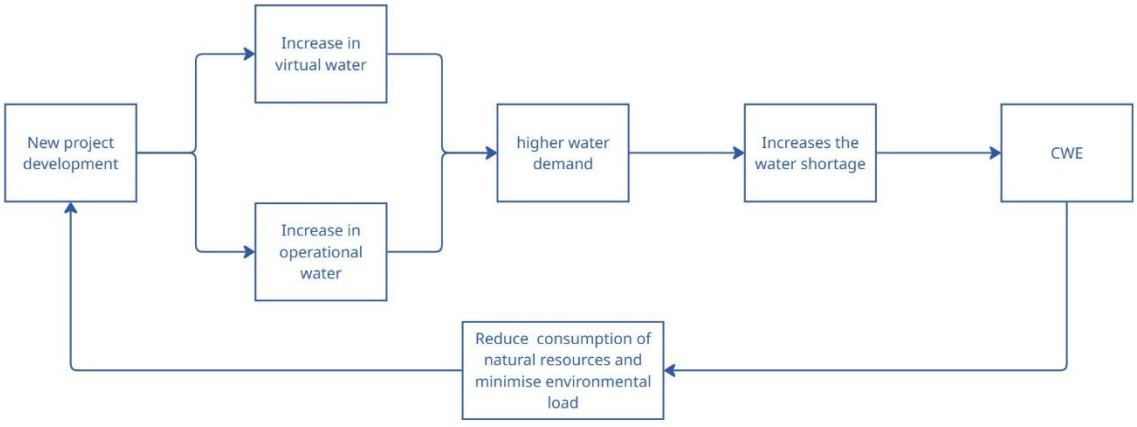

Figure 4 - Conceptual model (own design)

As scarcity grows, the need for Circular Water Economy (CWE) strategies become stronger. CWE acts as a counteracting mechanism reacting on the linear take–use–dispose economy. By reducing the use of natural resource consumption and minimising environmental load, circular strategies help reduce the impact caused by new development.

The cause and effects relationships shape the role of water within the project. The Q-T-I framework does not represent an additional step within the model, but rather a lens that explains the mechanisms behind the model. It shows that the role of water is not defined by volume alone, but by the timing and spatial impact of water use across the system. To understand where in interventions are most effective, the research applies the Q-T-I framework.

Using the Q-T-I framework links technical assessment of virtual and operational water to effects that CWE aims to reduce. It highlights that the role of water depends on how much, when and where impacts occur.

Finally, the model includes a feedback loop; insights into water use help identify suitable circular water-saving solutions, and these solutions influence how future projects are developed. This means that water use is not fixed, but can be actively shaped as part of the design and development process.

To give an overview of the research topic beyond the conceptual model a graphic visualisation is shown in Figure 5 that shows the different levels and phases of understanding the role of water in residential building projects forms the basis for developing (circular) water-saving solutions for the project implementation.

Figure 5 – Research visualisation (own design)

3. Research methods

This chapter outlines the research methods used to examine the role of water in high-rise residential development. It explains how the research method, the Lomanlaan case study, data analysis, calculation and interviews with project developers, contractors, material manufacturers and water-technology experts were conducted. Together, these methods provide the basis for analysing water use in material production and the operational phase, drivers and barriers for implementation and for identifying how developing contractors can implement (circular) water-saving solutions in practice.

3.1 Research approach

This research examines the role of water during material production and the operational phase of a high-rise residential development projects in the Netherlands. The first part of the main research question is addressed through both quantitative and qualitative analysis, focusing on water use in material production and the operational phase. A method suitable for identifying patterns, volumes, and relative impacts across materials and lifecycle stages (Ghanad, 2023). In this study, the data combined with interviews clarifies how much water is used, when it is used, and where the largest impacts occur, thereby answering the question:

“ What is the role of water in residential high-rise buildings during material production and the operational phase and how can developing contractors operationalise (circular) water-saving solutions into their projects?’’

The second part of the research question is addressed through qualitative analysis, which builds on the findings of the first chapter for analysing the role of water. Semi-structured interviews explore which water-saving solutions are currently feasible and what barriers and drivers are in place for why some are adopted while others are not, and where the greatest implementation potential lies during both material production and the operational phase. Qualitative methods are essential for understanding decision-making, organisational behaviour and on-site implementation challenges that cannot be captured through numerical data alone (Oranga & Matere, 2023). By combining both approaches, this study links quantified water impacts to practical impact and strategies for integrating (circular) water-saving solutions for developing contractors. The methodological steps of this design, literature review, case study analysis, tool assessment and exploratory interviews are shown in Figure 6**.**

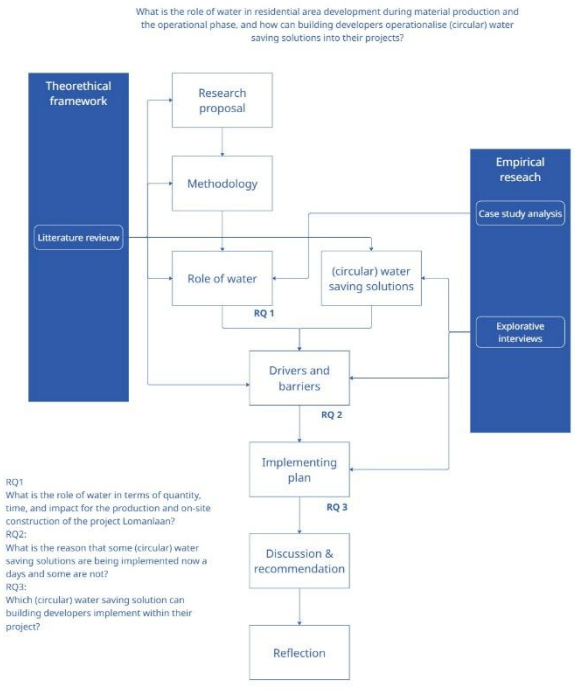

Figure 6 - Methodological framework (own design)

3.2 Data collection and analysis

3.2.1 Literature review

The literature review provides the basis of knowledge needed to analyze the role of water in high-rise residential development. It focuses on defining key water concepts (blue, green, grey and virtual water), understanding Dutch water problems with potable water, scarcity and excess, and identifying how water is used across the building life cycle. Scientific sources were collected through Scopus and Google Scholar, complemented by sector reports, supplier data, EPD's, Ecoinvent and the Milieudatabase for material-specific water values.

This review also clarifies why the topic is relevant beyond ERA Contour. As described in the introduction, high-rise housing is becoming increasingly common in the Netherlands due to urban densification, land scarcity and population growth (Al-Kodmany, 2022; Abbood et al., 2021). These developments increase both operational water demand and the embodied water impacts of material-intensive construction. Combined with growing freshwater shortages (Van Leerdam et al., 2023), this makes water use in high-rise projects a broader societal challenge.

3.2.2 Case study

The case study provides the reference point for analyzing the role of water during material production and the operational phase. The selected project, Lomanlaan in Utrecht, is part of ERA Contour's portfolio and represents a typical Dutch high-rise development which is increasingly common as introduced earlier. The project involves the demolition of an existing office tower and the construction of two new residential towers with 215 rental apartments, an underground parking garage and commercial functions on the ground floor. Its location next to a park and waterway makes it particularly relevant for studying water-related impacts. Beneath in Figure 7,Figure 8 and Figure 9 you can see the previous building next to the waterway, the new buildings and the project location on the map.

Figure 8 - New building (ERA artist impression)

Figure 9 - Old building (by de zwarte hond architect)

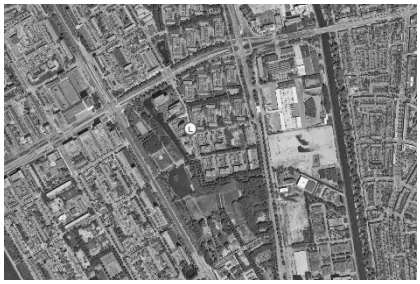

Figure 7 - Project area (google maps)

3.2.3 Exploratory interviews

To support and explore the first question on what is the role of water and further answer the second and third research questions, why some (circular) water-saving solutions are implemented while others are not, and how developing contractors can integrate these solutions into their projects, exploratory, semi-structured interviews were conducted with practitioners from the Dutch construction and development sector. Participants included project developers, contractors, material manufacturers, water-technology experts and frontrunner organizations working on circular water strategies.

The interviews followed a predefined set of open-ended questions, while still allowing room to explore unexpected insights and dive into interesting topics that come across. The full interview protocol and consent form are provided in Appendix 3. The conversations focused on barriers and enablers for applying water-saving solutions, the negotiation position of developing contractors, practical challenges in design and procurement, and examples of promising circular water applications. For materials identified as water-intensive in the case study, additional questions were asked to understand where contractors can influence reductions, either directly through design and procurement choices or indirectly through supplier engagement and organizational processes.

All interviews were recorded, transcribed and pseudonymized. The summaries and key takeaways of each interview are included in Appendix 4. The interview data was scanned to identify recurring themes and insights, which complement the quantitative findings from the case study and support the development of practical recommendations for reducing water use in high-rise residential projects.

3.2.4 Tools/calculation

For the assessment of the role of water different tools that are on the market were analysed. The tools assessed: Milieu Prestatie Gebouw (MPG), Environmental Product Declaration (EPD), Building Circularity Index (BCI) and Sima Pro. To compare these frameworks each was scored according to a scoring framework on a scale 0 to 3 for the three evaluation dimensions. These dimensions are coverage, reliability, and usability.

Coverage

0. No water-related functionality or not applicable
1. Water is mentioned but only partially included operational use or in material production
2. Water is included on both aspects with some details, but limited or incomplete
3. Water is fully integrated with clear, traceable indicators

Reliability

0. No data or completely unclear methodology
1. Data present but uncertain, averaged, or poorly traceable
2. Reasonably reliable; methodology partly transparent but with known limitations
3. High reliability; clear methodology, traceable data and consistent results

Usability

0. Not usable for project decisions
1. Limited usability with required expert interpretation
2. Usable for several decisions but with constraints
3. Highly usable; intuitive, actionable and directly applicable

GPR MATERIAAL

The GPR-software is the primary tool used within ERA Contour to perform MPG-calculations and assess CO_2-emissions at the project level. The tool is relatively user-friendly, and employees receive internal training to ensure they can apply it effectively in their daily work. ERA Contour intends to expand the use of GPR-software across more project teams so that a wider group of employees can test alternative materials and evaluate their impact on project-level CO_2 performance.

Although the full MPG-calculation is most of the time carried out by an external consultancy, GPR-software is used internally to adjust design choices and assess how these changes influence the CO_2-emissions per m^2. In principle, the tool could also support water-related assessments, as the underlying Milieudatabase includes water-use indicators in the new A2-set. However, these indicators are not yet reflected in the tool's output, meaning that water use cannot currently be evaluated through GPR-software (Table 1).

Based on these characteristics, the tool is scored as follows:

Table 1 - GPR materiaal (own table)

Tool	**Coverage**	**Reliability**	**Usability**
GPR materiaal	1	2	1
	The tool focuses primarily on CO_2 and MPG; water indicators exist in the database but are not integrated into the tool's output.	The tool is widely used, supported by the Milieudatabase, and externally validated for MPG calculations, but water-related reliability cannot yet be assessed.	The interface is accessible and employees receive training, but the lack of water-related outputs limits usability for this research purpose.

GPR WATERGEBRUIK

The GPR Watergebruik module is currently being expended to include a new calculation tool for daily drinking-water use per person, based on the European Level(s) framework. The tool is still under development and tested within and outside the project team. While promising for the operational phase analysis its current scope remains limited and the reliability of its outputs cannot yet be fully evaluated (Table 2).

Table 2 - GPR watergebruik (own table)

Tool	Coverage	Reliability	Usability
GPR watergebruik	1	2	2
	Only covers operational water use; material-related water use is not included.	Built on Level(s) methodology, but still under development	User-friendly interface, but functionality is incomplete.

BCI GEBOUW

BCI Gebouw is a broad sustainability tool that gives insight into many indicators, such as MPG, MKI, GWP, circularity, bio-based content and material reuse. Because it covers so many topics, it was also checked to see whether it could be used to calculate water use. Water scarcity (WDP) is included in the new A2-set, but the tool does not show this clearly in its reports. It only appears as numbers in the climate-effect report, without explanation or visualisation (Figure 10).

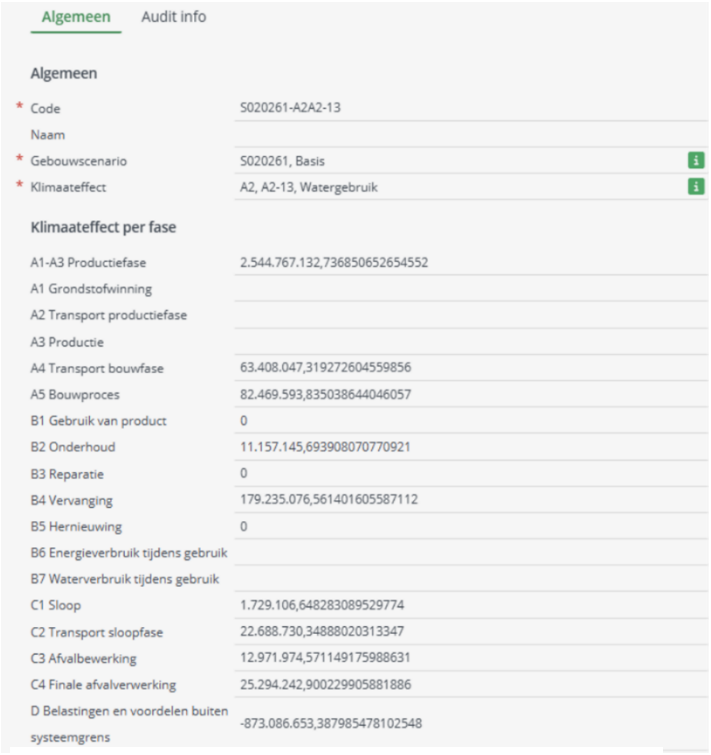

Figure 10 - BCI gebouw calculation Lomanlaan (own calculation)

The tool uses the AWARE factor (Boulay et al., 2018), which shows how much using water in a certain region may limit other users. However, many products do not have detailed regional or seasonal data, so the tool often uses average or substitute values. This makes the results less reliable. The extremely high WDP values found for the Lomanlaan project (2.5–3 billion m³ world-eq. deprived) show how difficult it is to interpret these outcomes in a meaningful way (Table 3).

Table 3 - BCI gebouw (own table)

Tool	Coverage	Reliability	Usability
BCI	1	1	0
	Water is technically included but not meaningfully integrated into the tool's reporting.	Strong methodology (AWARE), but inconsistent data quality and limited transparency.	Water results are difficult to interpret and not presented in a usable format.

SIMA PRO

SimaPro is a well-established LCA tool capable of analysing full life-cycle impacts, including water use. It provides detailed insights into material-level water flows and allows country-specific modelling using the AWARE factor. However, its level of detail makes it too explicit for whole-building water assessments, and interpreting water-depletion results requires expert knowledge.

An interview with an LCA expert (30+ years of experience) provided practical insights into how SimaPro works and how water use is calculated. In the example shown in Figure 11, a concrete block was analyzed for its water use (m³ deprived) across its life cycle. The expert emphasized that SimaPro is very useful when analyzing one specific material, such as concrete, but not suitable for modelling an entire building:

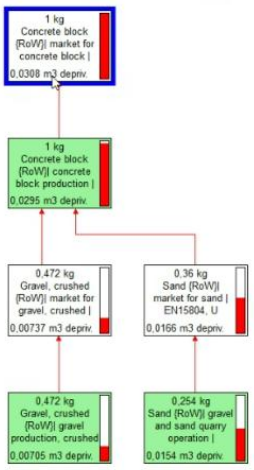

Figure 11 - Sima pro calculation concrete block (own calculation)

''But this instrument is not efficient to feed with the entire building.''
-Interview 1 LCA expert

SimaPro does show water use and many related processes, such as electricity and material flows. However, the total water-depletion score often appears small, while the underlying flows are large and sometimes even negative. These negative values represent water in- and outflows in processes like sand washing or equipment cleaning. This makes interpretation difficult. The expert concluded:

"I realize that that could be a good reason not to focus on that water depletion factor in the first place, because it is simply relatively unreliable."
-Interview 1 LCA expert

Like BCI Gebouw, SimaPro also uses the AWARE factor, which adjusts water impacts based on regional scarcity. Although this allows very precise modelling at material level, it is too detailed and too unstable for assessing the overall role of water in this research and therefore scored low on several levels as shown in Table 4.

Table 4 - SimaPro (own table)

Tool	Coverage	Reliability	Usability
Sima Pro	3	2	1
	Very detailed material-level water data.	Strong LCA basis, but water-depletion results are methodologically unstable.	Requires expert knowledge; not practical for project teams.

ENVIRONMENTAL PRODUCT DECLARATIONS EPD

All three tools (GPR, BCI, SimaPro) rely on EPDs as their primary data source. EPDs provide product-specific environmental data, including freshwater use (FW), but they rarely specify where water is used in the production process or what type of water is consumed. Public availability is limited and it is a time consuming work to gather all of the material EPD's by manufacturers.

Despite these limitations, EPDs remain the most transparent and product-specific source for water-related data and form the foundation for all tool-based calculations (Table 5).

Table 5 - EPD (own table)

Tool	Coverage	Reliability	Usability
EPD	3	2	2
	Covers full life-cycle stages with product-specific data.	Standardised and verified, but often lacking detail on water types and locations.	Clear structure, but interpretation of water indicators requires additional analysis.

CONCLUSION

Across all tools, the quality and usefulness of water-related data differs a lot. Some tools include water indicators but do not show them clearly, while others give very detailed results that are hard to interpret. Because of these limitations, this research follows one clear data strategy. Whenever possible, water data will first be taken from manufacturer-specific Environmental Product Declarations (EPDs), because these give the most accurate, product-level information. If no EPD is available, the Milieudatabase will be used, as it provides standardised values for the purpose of this research that is no problem if it is not a specific material. To understand the meaning of these numbers, all data will be compared with scientific research on virtual water consumption, so the results are placed in context and checked against international studies. This combined approach makes the assessment of the role of water in terms of quantity, time and impact during material production as consistent and transparent as possible, despite the current limits of the available tools.

To quantify virtual water use in material production for the case project, the Bill of Quantities (BoQ) was used as the primary input. The BoQ lists all materials used in the project, including volumes, weights and specifications. This makes it a crucial dataset for linking material quantities to water-use data from:

- Environmental Product Declarations (EPDs)
- the Milieudatabase
- scientific literature on virtual water
- supplier information

By combining the BoQ with water-use data, the analysis identifies which materials contribute most to the project's water footprint and where the largest reduction potential lies. This structured approach ensures that the assessment is both understandable for people if they can see what is built and grounded in real project data rather than generic assumptions.

3.3 Analytical focus

This thesis takes the building scale as its central analytical unit, with a specific focus on the material production phase (A1–A3) and the operational phase (B1, B6 and B7) of high-rise residential buildings. High-rise is selected because it is an increasingly dominant typology in Dutch urban development and presents unique spatial and technical constraints for implementing circular water strategies. These constraints make high-rise both a challenging and highly relevant context for analyzing water use.

The analysis begins at the material level, identifying water-intensive components such as aluminum, concrete and brick, materials that are either widely used or known for their high virtual water demand. These material-level insights are then aggregated to the building level to determine the total water footprint. This building-scale assessment is subsequently linked to regional water availability, acknowledging that the urgency and feasibility of circular water strategies differ across Dutch regions facing varying degrees of water scarcity.

The scope is deliberately limited to the phases and scales where developing contractors have influence. Their leverage in material production is indirect, but they can influence procurement choices, design decisions and supplier engagement. Their influence is stronger in the operational phase, where technical and behavioral water-saving measures can be implemented. Due to time constraints, the research focuses on a shortlist of feasible solutions, prioritizing those that are technically possible and, where relevant, financially realistic.

3.4 Data Management Plan & Ethics

This research follows the ethical standards of TU Delft and complies with the General Data Protection Regulation (GDPR). Ethical considerations mainly relate to the semi-structured interviews conducted with project developers, contractors, material manufacturers, water-technology experts and frontrunner organizations working on circular water solutions. All participants received an information sheet and signed an informed consent form prior to the interview. They were informed about the purpose of the study, their right to withdraw, and how their data would be handled. Interviews were audio-recorded with permission and transcribed pseudonymously. Participants were given the opportunity to review their transcript before finalization. No interviewee made use of this rule.

All data were managed according to the approved Data Management Plan. Audio recordings were stored temporarily on a secure device and deleted immediately after transcription. Transcripts, pseudonymized datasets and consent forms were stored on TU Delft OneDrive, with access restricted to the researcher and supervisors. Personal data were stored separately from research data to minimize the risk of re-identification and will be deleted at the end of the project. Only pseudonymized quotes may appear in the final thesis and the summary of the interviews. No raw interview data will be publicly shared.

The study does not involve vulnerable groups or sensitive topics and is therefore considered low-risk. Through informed consent, pseudonymized and secure storage, participant privacy and research integrity were safeguarded throughout the project.

4. Results

This chapter follows the research theories and information gathered in the literature study and puts this into practise. First the role of water is calculated through the multidimensional framework in terms of quantity, time and impact for the material production and operational phase. Followed by the drivers and barriers why some are being implemented nowadays and others are not. Lastly the implementation plan for the company focused on its project for reducing the role of water and optimizing the resources (Arai et al., 2024).

This chapter presents the results of data and already present research combined with 11 semi- structured interviews with different stakeholders within the built environment (Table 6). The conducted interviews give insights and explore what prevents (circular) water-saving solutions from being implemented and what feasible possibilities are being implemented.

Table 6 - Interview respondents (own table)

Interview number	Function interviewee	Duration
1	Consultant sustainable concrete & coordinator sustainable solutions	48:40
2	LCA expert	1:06:25
3	Specialist sustainability and legislation & coordinator sustainable solutions	27:40
4	Director urban concrete recycling & coordinator sustainable solutions	1:02:00
5	Area developer	45:15
6	Adviser/ researcher water	41:20
7	Sales director smart metering tool	53:10
8	Professor with knowledge of sustainable housing	30:55
9	Senior Policy Advisor Public Law & Coordinator SVHC	1:00:35
10	Regional sales manager greywater recycling	31:30
11	Site manager high rise residential building	1:30:30

4.1 Role of water

Understand where water-saving solutions can meaningful reduce water-use requires insights into how water is used across the building life cycle. This section applies the Q-T-I framework. Quantity refers to the total volume of water involved (m^3). Time reflects when and for how long water is required across the building's life cycle, based on the EPD phases (A, B, C & D). Impact considers where water use affects different spatial scales, from the building to the national level. The framework is applied to the Lomanlaan case project, a representative high-rise development consisting of two residential towers. The analysis distinguishes between material production (virtual water) and operational water use, providing a basis for identifying where interventions are most effective and where current barriers limit implementation.

4.1.1 Quantity

MATERIAL PRODUCTION

The quantity dimension refers to the total volume of water required for the material production, expressed in cubic metres (m^3). This chapter analyses the quantity for the material production per unit, for the case study and within the Dutch building sector of 2030. Embodied water, also referred to as virtual water, captures all water consumed throughout extraction, processing and manufacturing. Although reported values vary across studies as shown in Table 7, due to differences in construction methods and regional water availability, they consistently show that material production represents a substantial share of a building's total water footprint.

Table 7 - Virtual water material production (own table)

Research	Country	Virtual water	Included
Heravi & Abdolvand (2019)	Iran	20.8 m^3/m^2	Construction
Bardhan (2011)	India	27.6 m^3/m^2	Structural components
(Satthya, 2023).	India	26 m^3/m^2	High-rise buildings

To estimate the embodied water of the Lomanlaan project, averaged values from international studies were applied to the project's gross floor area (22.923 m^2). This results in an estimated 570.115 m^3 of embodied water. While this number reflects an average across different contexts, it provides a reasonable indication of the scale of water use embedded for the material production in the high-rise construction of the Lomanlaan project.

To further specify the contribution of individual materials, a selection of high water-impact components was analyzed. The shortlist was based on two criteria:

1. materials that dominate the building's environmental impact in CO_2-reduction studies
2. materials known to have high embodied water or large material volumes in high-rise projects.

This resulted in three key materials for further analysis: aluminium, concrete, and brick. These materials differ in their water intensity but collectively represent the most relevant contributors to the project's embodied water footprint.

Aluminium window frames

Aluminium stands out as one of the most water-intensive materials in the project. Literature shows that metals, and aluminium in particular, have disproportionately high embodied water compared to materials such as brick or concrete. Crawford & Pullen (2011) report a virtual water contribution of 1.084 m^3/ton, making it one of the most water-demanding construction materials. This aligns with broader findings that metal production dominates the water footprint of building projects; for example, steel and cement together accounted for more than 75% of the total water footprint in a commercial building project in Beijing (Crawford & Pullen, 2011; Han et al., 2016).

For the Lomanlaan project, the water demand of aluminium window and door frames can be estimated in two ways:

- EPD-based value: 15 m^3 world-eq. deprived water per m^2 (Stichting Nationale Milieudatabase, n.d.)
- Material-based value: 1,084 m^3/ton, combined with an average frame weight of 9.48 kg/m^2 (≈ 9 m^3 water per m^2) (Crawford & Pullen, 2011)

On average this means 12 m^3/m^2 window frame. With 3,925 m^2 of aluminium frames in the project, this results in:

- 58,877 m^3 world-eq. deprived water (EPD approach)
- 36,540 m^3 of water (research material-based approach)

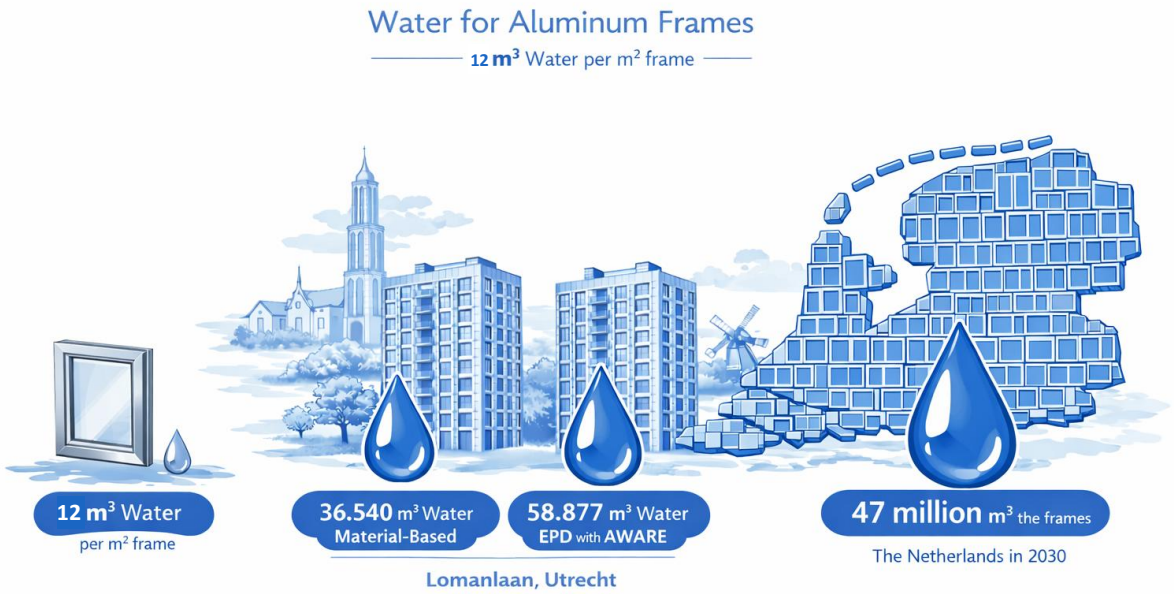

Figure 12 - Water quantity aluminium window frames (own image)

The difference between these values is primarily due to the AWARE factor, which adjusts water consumption based on regional scarcity (Serafini & Ciroth, 2024). Despite this variation, both methods confirm that aluminium contributes significantly to the project's embodied water footprint and represents a material where early design and procurement decisions strongly influence total water demand. The complete visualisation and comparison is shown in Figure 12.

Concrete

For a 20 MPa concrete mix it requires between 11 m^3 of water per m^3 (Crawford & Pullen, 2011) up to 30 m3/m3 for when using the Water Depletion Potential (WDP) indicator from EPD calculation. Most of the EPD's found for this research are close to 11 m3, which is therefore used as the basis for the concrete calculations (Figure 13).

For the Lomanlaan project, applying this value to all structural elements results in 98.000 m^3 of direct water use and 110 m^3 world-eq. deprived water according to the EPD.

Concrete also represents the largest material volume used in the Netherlands toward 2030 (Arnoldussen et al., 2026). Nationally, concrete remains the dominant material flow, with an estimated 85 million m^3 of water demand for concrete production in 2030 when applying the average water-use value per cubic meter.

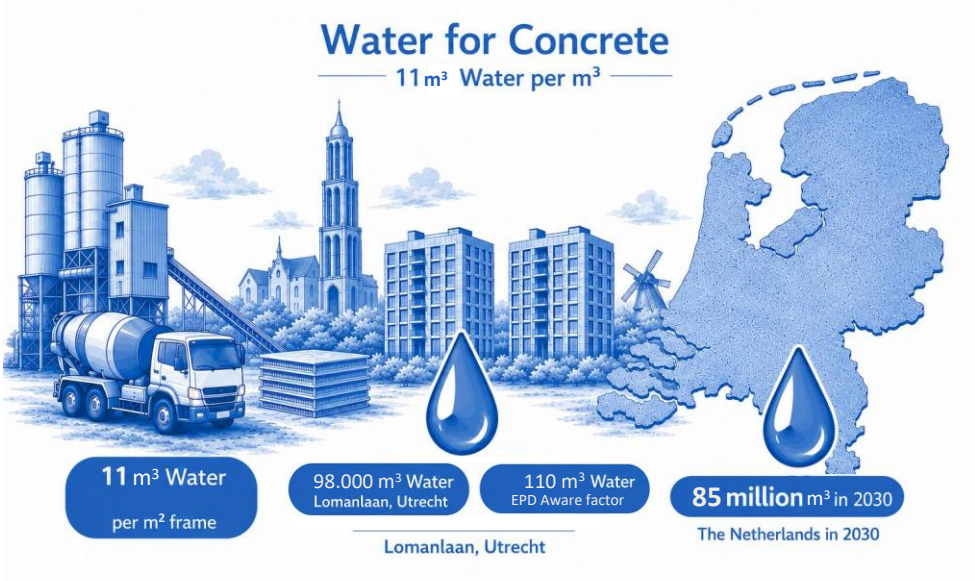

Figure 13 - Water quantity concrete (own image)

Bricks

Bricks have a relatively modest but still relevant embodied water footprint compared to metals or concrete. The average water requirement for fired clay bricks from Crawford & Pullen (2011) is 0,69 m³ per m² of façade. Applied to the Lomanlaan project, this results in approximately 5.747 m³ of water. When using EPD values for the A1–A3 production phases, the footprint is at 37.410 (4,5 m3 per m2) m³ world-eq. deprived water, reflecting the influence of regional scarcity factors included in the AWARE method (Figure 14). The choice of bricks has big implications for this value as other bricks appear to be much higher.

At the national scale, brick production is expected to increase slightly towards 2030 before declining towards 2050 (Arnoldussen et al., 2026). For 2030, the projected water demand for all brick façades in the Netherlands is approximately 4.3 million m³. Although this is significant at the national level for bricks, the impact at the project level remains relatively small compared to more water-intensive materials such as aluminium.

Figure 14 - Water needed for bricks info (own design)

OPERATIONAL PHASE

The operational phase covers the potable water used by residents during the building's lifetime, which is assumed to be 75 years (W/E adviseurs, 2013). In the Netherlands, household water consumption has remained relatively stable, with an average use of 128,1 litres per person per day (LPPPD). Most of this water is used for daily activities: showering (36%), toilet flushing (24%), and washing machines (13%); only 2% is used for human consumption of actually drinking (CBS, 2023).

To understand the implications for the Lomanlaan project, national averages were applied to the building's 215 dwellings. At the start of 2025, the Netherlands had 8.2 million households and an average of 2,10 people per household (CBS, 2025). This means for the Lomanlaan project, that contains 215 dwellings, with 2 and 3 room apartments, a total number of residents estimated at:

$$215 \times 2{,}10 = 452 \text{ residents}$$

With each person using 120 litres per day, the total annual water use for the building is:

$$(452 \text{ residents} \times 128{,}1 \text{ L/day}) \times 365 \approx 21.000 \text{ m}^3\text{/year}$$

This provides a clear baseline for comparing operational water use with the embodied water in the building materials of the case project. As shown earlier, the embodied water used for the realisation of the high-rise residential tower requires 570.115 m³ of water, which equals approximately 29 years of operational water use. Over a 75 year lifespan, the total operational demand amount is:

$$21.134 \text{ m3/year} \times 75 \text{ years} = 1.585.045 \text{ m3}$$

This means that operational water use accounts for roughly two-thirds of the building's total water footprint, while one-third is embedded upfront in material production. The operational phase therefore represents the largest long-term opportunity for reducing potable water demand, especially given increasing pressure on regional water supplies. This comparison highlights two important insights. First, the operational phase offers the greatest potential for long-term reductions in potable water demand, especially given increasing pressure on regional water supplies. Second, the embodied water footprint is largely determined by early design and procurement decisions, highlighting the importance of critical material selection in the initial stages of development. Together, these findings provide a clear foundation for identifying meaningful water-saving strategies in both the construction and use phases of high-rise residential buildings.

4.1.2 Time

The previous chapter examined the quantity of water. This chapter focuses on timing: when water use occurs, why it peaks at certain moments, and how timing influences decision-making in residential projects.

MATERIAL PRODUCTION

Across all of the materials for the Lomanlaan project, the timing of water use, is primarily concentrated in the A1–A3 production phase, long before construction begins. Both the BCI tool and existing literature show that the most water-intensive activities take place upstream in industrial production rather than on-site Han et al. (2016). The three selected materials are highlighted within the timing aspects

ALUMINIUM

Production process: Water plays a continues and critical role throughout the entire A1–A3 material production. Large volumes of high-purity water are required for cooling, at multiple shaping, and cleaning (Vandenryt, 2026). These processes run in repeated industrial cycles over days to weeks, meaning water use is not concentrated in a single moment but across the full production timeline. This makes aluminum one of the most water- and energy intensive materials (McCormack et al., 2007; Crawford & Pullen, 2011).

This pattern aligns with broader life-cycle research showing that embodied water in metal production is significantly higher than water used during construction or operation (Crawford & Pullen, 2011; Han et al., 2016).

Material selection: The timing of the material selection is not only a technical decision, but a multi-criteria decision shaped by environmental, economic, and performance considerations. For window frames, this decision is made early in the design process and involves multiple stakeholders.

External influences also play a role. Municipal requirements, client ambitions, budget constraints, and technical feasibility all shape the final material choice. Limited policy support and lack of awareness can act as barriers, while governments can steer decisions through standards and incentives (Appendix 5).

Lifecycle: At the end of the lifecycle, aluminum also offers strong recycling potential. It is durable, highly recyclable, and design for disassembly can help preserve material value (Asif et al., 2005). However, reuse, reconditioning, remanufacturing, and recycling do not have the same environmental value, and that keeping materials in use for longer usually retains more value than recycling them (King et al., 2006).

Overall, this shows that the water relevance of aluminum in residential projects is primarily decided upstream, during material production and early design choices. The greatest opportunity to reduce water impact lies with those manufacturing the frames, shaping the brief, specifications for possible less water demanding frames like wood, and approval process, while end-of-life strategies mainly influence future impacts.

CONCRETE

Production process: For concrete, the timing of water use is determined in the A1-A3 phase by binder production, batching, washing, and the choice of mixture. Netz & Sundin (2015) show that washing the mixer accounts for 72% of water use, compared to 16% for cement production, confirming that washing dominates the timing of water demand within this phase. For the quantity of concrete calculated in chapter 4.1.1. according to research this should be 11 m^3 for 1 m^3 concrete. The concrete expert indicated that around 150 L of mixing water per m^3 is common. This water was shown on site to be harvested rainwater from the roofs of the prefab factory or industrial water that will also be reused in washing cycles. Across production and recycling the concrete water use appears as a repeated, ongoing demand, not a single moment in such a factory and recycling plant of the concrete.

The concrete mixture also influences water timing. Using supplementary cementitious materials (SCMs) such as slag or fly ash can reduce water demand by lowering cement content but this also lowers the workability (chapter 4.3.1).

Material selection: Choosing concrete as the structural base of the project fixes most water impact early in the design process. The choice on which structural system has big implication on the structural constraints such as span length, acoustic requirements, and fire performance limit the ability to switch systems later. This was highlighted during interviews that optimization and conversation needs to be started early to bring a real impact for the CO^2 reduction this is also the case. This means that clients, designers, engineers, and tender teams influence the water footprint of concrete long before batching start (Rahle et al., 2021).

Life cycle: Concrete reuse potential is improving, with companies such as Urban Mine and Renewi developing recycling processes from urban harvested concrete. However, compared with materials that can be easily disassembled, concrete still requires significant processing effort.

Assessing the water footprint for sustainable construction and deconstruction should be considered together with embodied carbon and resource depletion, as material choices affect all life-cycle stages from A to D (Khasreen et al., 2009). Overall, the largest opportunity to reduce the water impact of concrete lies upstream, during production, in the early design and procurement choices that determine the mix recipe.

BRICKS

Production process: Brick production uses both direct and indirect water, required for raw material extraction in A1, the most water-intensive stage, and for shaping, mixing and cleaning during moulding in A3 (Skouteris et al., 2018). Firing methods, aggregates choice and the finer the brick is strongly influence both the water and carbon footprint, as they determine drying time, energy demand, and material composition (Islam et al., 2023; Dabaieh et al., 2020). This means again that for bricks the water relevance is fixed before construction begins, with A1–A3 determining almost the entire embodied water load.

Material selection: Brick façades remain a common building material in the Netherlands for facades, although their structural role has decreased over time (Sprecher et al., 2022). Material selection therefore involves choosing between choices like fired clay bricks, sun-dried bricks, recycled aggregates, or bio-based alternatives, each with different water demands (Islam et al., 2023). Aesthetic requirements such as colour and texture also influence the final choice, indirectly shaping the water footprint through the production route selected.

Life cycle**:** At the end of life (B4), the water footprint of bricks is minimal because the main water burden is already embodied in the material. Although construction and demolition waste is substantial, over 10 billion tonnes annually, more than 75% has residual value and can be reused or recycled (Caro et al., 2024).

For bricks, end-of-life strategies influences reuse potential rather than reducing embodied water. In conclusion, the key timing for meaningful reduction lies in A3 production and early material selection, where firing methods, fuel types, and aggregate choices determine most of the water footprint.

OPERATIONAL PHASE

During the operational phase, water use follows clear daily and seasonal patterns which affect the use of water within a timely matter. For the timing during the day it shows a logical pattern that households use the least water at night, with strong peaks in the early morning and early evening when people shower, cook, clean, and use appliances (Beal et al., 2013;Phernambucq et al., 2023).

Seasonal changes have a big influence. Dutch potable water use increases by about 6% in warm and dry months, and in very dry years this can rise to almost 20% per month because of garden irrigation (Phernambucq et al., 2023). This water use is mainly due to outdoor water use strongly linked to temperature, sunlight, and dry periods (Gato et al., 2007). People also change their behaviour: in warm weather they shower more often but for shorter periods, while in colder seasons showers tend to be longer (Beal et al., 2013; Paniccia & Vertommen, 2020) Weather conditions also affect short-term water use. Temperature and sunlight have the strongest impact, while humidity plays a smaller role and rainfall shows no clear relationship with consumption (Willis et al., 2013; Paniccia & Vertommen, 2020).

4.1.3 Impact

The impact of water is quite a broad term, but what do we mean with it. For this research the focus is on gathering insight on the impact of water for the material production process and for the operational phase. Connecting the impact at the different scales (chapter 2.1.6.), the type of water (chapter 2.1.5.) and if that impacts the water levels or potable water.

MATERIAL PRODUCTION

Each material carries its own water dependencies, ranging from extraction and processing to manufacturing and cleaning, shaping both direct freshwater use and indirect impacts on water quality and availability. By linking the type of water involved (blue, green, grey) with the scale at which impacts occur (project to global), this section examines how material choices influence water scarcity, potable water competition, and hydrological pressures across regions. The following subsections outline how aluminium, concrete, and brick production each contribute to these impacts in different ways.

ALUMINUM

For the production of aluminum window frames bauxite is needed as the main ingredient. The winning of Bauxiet impacts the surrounding city & region with contamination of potable water and other health risks (Lee et al., 2017). Global demand for primary aluminium is expected to keep rising. China remains the largest consumer until at least 2035 before stabilising, while India and other Asian and African countries rapidly increase their share (Europian Aluminium, 2019). For the construction industry, the demand for semi-fabricated aluminum is set to grow by twenty-eight percent by the year 2050 (Europian Aluminium, 2019). This means the environmental impact of aluminium production will remain highly relevant for building products such as window frames. Even though we see a high demand for PVC windows for residential houses at this moment a rise for aluminium windows is expected.

For the aluminum window frames used in the case project of the Lomanlaan project in Utrecht (The Netherlands) this impact is felt in a different country. However the impact of both the mining, melting, transportation and many other steps within the process of making the aluminum has impact on global warming and therefore impacts the water levels and potable water in The Netherlands and connects the different scales indirectly.

CONCRETE

Concrete production has indirect relationship with the use of potable water resources, as it uses blue water within its production which cannot be used anymore for drinking water. Standards such as NEN-EN 1008:2002 explicitly state that water for concrete must meet quality requirements similar to potable water, other water quality should be tested (NEN, 2002).

This was confirmed in the interviews, where it was explained that blue water from rainwater or industrial water is normally used. The use of brackish water, is generally discouraged as it can negatively affect the setting time of concrete and accelerate corrosion of steel reinforcement

concrete (Neville, 2012; NEN, 2002). For the visited concrete plant in particular, the canal next to the concrete factory contains brackish water. This type of water is present in large quantities across the world but can unfortunately not be used for this type of production with reinforcements within the concrete.

This reliance on fresh water means that concrete production competes directly with potable water supply, a concern that is becoming more urgent as global water scarcity increases (Van Leerdam et al., 2023). Academic studies estimate that the concrete industry is responsible for 9% of global industrial water, which is 20% of the total water consumption (Mekonnen & Hoekstra, 2016; Miller et al., 2018). Together with the largest material production in volume, it creates a big quantity due to its popular use (Arnoldussen et al., 2026).

Within the A1–A3 stages, studies show that washing concrete mixers and equipment can account for up to 72% of total water use in concrete production but is however reused in a lot of cases (Marinoski et al., 2018; Miller et al., 2018) Besides using water for mixing the concrete, washing the concrete mixers and equipment, the interview with the concrete expert emphasized that washing sea sand is likely an even more water-intensive process. An interesting insight especially as the use of marine aggregates is noted to increase.

BRICKS

When looking at the impact of water on the project level in this case project in Utrecht at the Lomanlaan. It's impact is low as brick production happens off site and has its highest water impact on site at the factory. When looking at the national level for brick factories, 37 factories are based within The Netherlands. Out of these factories most of them are based around the river Waal (Koninklijk verbond van Nederlandse Baksteenfabrikanten, 2011). The impact of water use for material production of bricks is strongly concentrated within this region of the factories.

For the brick factory in England it was found that producing one fired-clay brick requires 2.02 litres of water, of which 1.71 litres (84.8%) is blue water and 0.31 L (15.2%) green water (Skouteris et al., 2018). This shows that brick manufacturing relies heavily on freshwater and other water resources.

In addition to direct water use, brick production has indirect impacts through clay extraction, kiln emissions, and waste disposal. This can affect local water quality, especially in regions where brick kilns are densely concentrated and freshwater availability is already limited (Shamim et al., 2024). In The Netherlands this is starting to become a scarcity and possibly regions with more water or other techniques using brackish water could help by reducing the demand of water.

OPERATIONAL PHASE

The operational phase of residential buildings is responsible for about two-thirds of total potable water use (chapter 4.1.1.) over a building's lifetime. This demand has an impact on blue water resources; freshwater extracted from groundwater and surface water for potable water production. At the building level, this means daily consumption from showers, toilets, taps, and other appliances. When scaled up across neighborhoods and cities, this demand affects the district and regional level. Research from England and Wales shows that rising household water use is a major driver of future scarcity: the likelihood of water-use restrictions is expected to double by 2050 and become four times higher by 2100 (Salmoral et al., 2019).

Water utilities in water-stressed regions are already facing challenges in balancing supply and demand. In Figure 15 the map of The Netherlands is shown from Vewin (Vewin, 2022). Even though the map is dated 2022, it clearly shows the problems with the water supply has on these plans and when action should be taken. The area where the most action should be taken is around Utrecht.

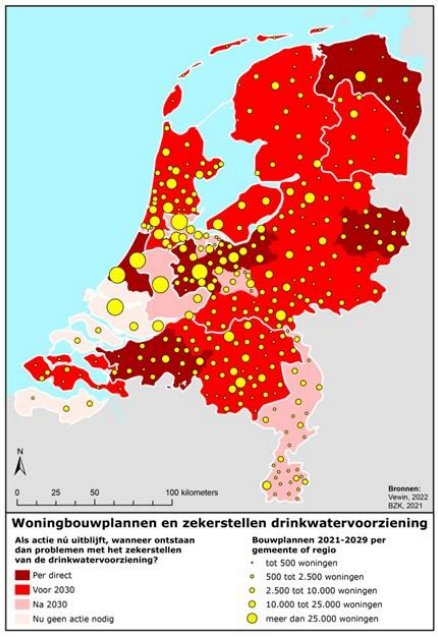

Figure 15 - Map of The Netherlands building plans and security potable water supply, (bron Vewin)

4.1.4 Conclusie

Water use in high-rise residential development is both large and largely invisible. The Lomanlaan case shows that the embodied water in building materials equals roughly 29 years of operational water use. This means nearly one-third of the building's total lifecycle water demand is already locked in before the first resident moves in. The timing analysis makes clear that the most important decisions happen early. Water use for aluminium, concrete, and brick is concentrated in the A1-A3 production phase, long before construction starts. Once the material choice is made during design, the water footprint is essentially fixed. You cannot go back and change it later.

The impact of water use plays out at different scales. Aluminium production often affects water resources in other countries where bauxite is mined. Concrete production in the Netherlands competes directly with potable water supplies, since mixing water needs to meet drinking water standards. Brick production puts pressure on regional freshwater sources around factory locations, mostly along the river Waal. Meanwhile, operational water demand affects local and regional potable water systems, especially in water-stressed areas like Utrecht.

Two main insights stand out. First, the operational phase offers the biggest opportunity for reducing potable water demand, since it accounts for roughly two-thirds of the total footprint over the building's lifespan and can be changed by the developing contractor. Second, the embodied water footprint is determined by early design and procurement decisions that are hard to reverse, which makes material selection in the initial project stages a critical leverage point. The people who hold this leverage are clients, designers, engineers, and procurement teams. Municipalities also play a role through permit requirements and sustainability ambitions. If water is taken seriously from the start, the biggest reductions can be achieved. If it is ignored until construction begins, most of the damage is already done.

4.2 Implementation drivers and barriers

This chapter gives insights into the drivers and barriers for the implementation of (circular) water-saving solutions for residential high-rise projects. Understanding why some (circular) water-saving solutions are being implemented in construction projects while others remain absent highlighted five different factors. These factors are analysed through academic literature and through the interviews. The five overarching themes that came forward are:

1. Knowledge and awareness
2. Municipal requirements and urban planning
3. Financial feasibility and returns
4. Rules and regulations
5. Execution and maintenance

These factors shape both the willingness and the ability of developing contractors to adopt (circular) water-saving solutions within their projects.

4.2.1 Knowledge and awareness

The first barrier for the implementation is the limited awareness of the scale and impact of water use during material production and the operational phase. As shown in chapter 4.1, the material production of the case project Lomanlaan consumes an amount equal to 29 years of operational water use. This amount often surprised practitioners during the interview sessions as shown in appendix 4. While awareness of CO_2 emissions has grown at the construction sector, awareness around water consumption has not. This lack of awareness is also seen at the developing contractor ERA Contour. The CO_2 reduction is supported at ERA Contour by internal initiatives such as green lists, sustainability coordinators, and cross-departmental groups like the “Green Rebels’’. Water remains far less visible; one of the reasons for this is the lack of knowledge and awareness.

This lack of awareness persists despite growing societal urgency. Dutch water utilities warn that long-term supply reliability can no longer be guaranteed due to climate-driven droughts and declining river flows (Van Leerdam et al., 2023). The sector already signals that, without structural reductions in potable water demand, and water-efficient houses it will be impossible to supply all 900,000 planned new homes (Drinkwaterplatform, 2025;Bouwtafel waterzuinige wijken, 2026)

International examples show that awareness can shift behavior. An example for this can be found in Flanders in Belgium. Where a combination of mandatory rainwater tanks, higher costs for larger water use and public information campaigns to create awareness was used. This has significantly reduced household water from 90,4 liter in 2013 to 80,8 liter per person per day in 2023 (Milieumaatschappij, 2024). Far below the dutch level of 128,1 litres of potable water per day in 2023 (CBS, 2023). The Belgium region of Flanders is a good example illustrating that awareness, combined with clear policy signals, can accelerate adoption.

For developing contractors, the low visibility of water impacts means that water-saving solutions rarely become a priority. Awareness is increasing, but unevenly, and this slows down the adoption of circular water systems.

4.2.2 Municipal requirements and urban planning

Municipalities increasingly use their application requirements to stimulate or require (circular) water-saving and infiltration strategies. Example projects like 'Linck in the Binck' in the Hague, 'Parkhaven' in Rotterdam and in area development 'De Venen' in Hoogveen demonstrate how municipal requirements can directly shape design choices. Looking at the municipality of The Hague which requires developing contractors to meet a climate-adaptation point system as part of the environmental permit. These requirements for water are:

- buffering 50 mm of short-term rainfall on the plot, and
- saving or reusing 50% of annual rainfall to address drought risks.

These requirements reflect the dual challenge of water excess and water shortage (Van Leerdam et al., 2023). For the acceptance of the environmental permit these requirements should be met and therefore creates a clear incentive for developing contractors to explore circular water strategies, aligning with the "forced pathway", in which regulation pushes organizations toward circular practices and creates an urgency for them to investigate and apply it in practice (Morseletto et al., 2022).

An example further away can be found in the city of Copenhagen. A city that is preparing for extreme climate events but has already experienced one on in 2011; where 150 mm of rainfall occurred in just three hours. With the countries topographic position in northern Europe, the city is already feeling the impact of climate change more rapidly (Bjerke et al., 2025). While preparing and adapting the city for the future it can also be seen as an opportunity. Lykke Leonardsen spoke passionate on the matter on Twitter;

"How can we create added value from a problem by not only solving the problem of water management, but actually seizing the opportunity to upgrade neighbourhoods"
- Lykke Leonardsen

Singapore is another city where they created a city-wide system in the urban planning. Previously being threatened with a shortage of potable water, they created several systems of harvesting, importing and recycling water. The city has central basins spread along the island and even found a way of making potable water out of sea water (Phong HO, 2023).

Thus, municipal requirements and urban planning can act as catalysts for implementation. Particularly when they are measurable, enforceable, and tied to permitting. A positive side effect is that adapting the built environment for future shortages and excess can directly upgrade neighborhoods.

4.2.3 Financial feasibility and returns

Even when awareness and urban planning incentives are present, financial feasibility remains a decisive factor for project feasibility. The Linck-project in The Netherlands is taken to illustrates this tension. The development team implemented a rainwater cascading system that irrigates green roofs and elevated gardens across the building. The system was divided into two circuits to reduce piping costs while maintaining functionality.

However, this system has to be maintained. Thus creating long-term maintenance costs besides the initial investment. The maintenance costs were highlighted by the project developer to increase the service costs by approximately €40 per month, on top of existing fees. These operational and maintenance costs are a barrier for the adoption of circular water systems and have a long return period (Amado & Barroso, 2013;Riazi et al., 2023).

More advanced systems, such as greywater reuse like Hydraloop installations, face even greater financial barriers. The additional costs of the piping needed for the system cost around €2,500 per apartment from the interview of a site manager. While the annual savings from reduced water use amounts to only €43 per household per year (based on Waternet's 2026 tariff of €1.03/m^3). This results in a payback period of nearly 60 years, excluding maintenance and initial costs of the machinery. This payback period is far beyond typical investment horizons and buildings lifespan (75 years).

Developers therefore face a structural mismatch: water is too cheap to justify expensive circular systems, even though water scarcity is increasing. At the event Living with water in the climate of the future (KAN bouwen, 2026) Yvonne van Mierlo from developer Blauwhoed noted:

"We want to do more, but it simply does not fit the real-estate business case"
- Yvonne van Mierlo, 2026

A common view of the sector is the financial feasibility struggles of initiatives; it was mentioned in six of the eleven interviews done for this research. Even though the financial feasibility at the current date seems not possible, optimism towards the future and interesting resemblance with the once unfeasible solar panels shows some positivity. Another area developer made the resemblance with the implementation process of solar panels and noted:

''The comparison with solar panels is easy to make. You earn back those extra costs.
Potable water is very cheap…. It is not a business case.''
– 5. Area Developer

Compared to other projects such as 'Little C' in Rotterdam, where retention crates were installed per roof surface but not connected across buildings, the Linck-project shows a more integrated approach. Yet the system remains limited to irrigation rather than broader greywater reuse, reflecting regulatory constraints, expansive execution and non-mandatory rules in the current Dutch Drinkwaterbesluit and Bouwbesluit (Rijksoverheid, 2024). During the interview the site manager highlighted the complexity and costly measures that come with possible greywater systems for systems like water storage beneath the building.

''..that is all full beneath the building. To be able to buffer your water which you will need a lot of you
have to go into the ground, and then it is a very expensive solution
Then it is not cost-effective, because you reach your water level.''
– 11. Site manager residential high-rise project

4.2.4 Rules and regulation

Regulation plays a dual role: it can both enable and restrict circular water solutions. In the Belgium area of Flanders, mandatory rainwater tanks for new construction have proven highly effective in reducing potable-water demand (Armeni, 2008). During interviews the example of Belgium was mentioned often and how it really helped to reduce the potable water demand. In the Flemish region they are improving water savings in domestic consumption through water-pricing mechanism that depend on your water use (Armeni, 2008). When talking about the costs and regulation it was mentioned that:

> *''I think legislation is the most important factor, because the costs are really pushed aside when an obligation arises from the law.''*
> – 7. Sales director smart metering tool

This was reflected in more interviews that were held and mentioned often as one of the tools to really start decreasing the water use demand and to start seeing the value of water. In the Netherlands, however, the Drinkwaterbesluit currently restricts the use of rainwater and treated greywater for household applications (Vewin, 2022). As a result, many promising circular systems cannot be legally connected to toilets or washing machines. A exemption can be asked but takes up time, money and effort to get this.

At the same time, regulatory pressure is increasing. The Netherlands is expected to miss its 2027 ''kader richtlijn water (KRW) targets, which may lead to fines and stricter permitting (Groothuijse & Van Rijswijck, 2023) From 2027 onward, this could result in:

- Restrictions on dewatering,
- Additional testing requirements,
- Delays in environmental permits, and
- Higher project risks (Phernambucq et al., 2023)

Water utilities already warn that in some regions, new large-scale connections cannot be guaranteed (Van Leerdam et al., 2023;Drinkwaterplatform, 2025) This creates a growing risk that water availability becomes a bottleneck for new housing developments.

Evidence from other industries supports this mechanism. The paper and textile sectors, for example, have progressively adopted water-saving technologies in response to regulatory pressure and rising water prices (Hasanbeigi & Price, 2015). In construction, similar dynamics are slowly emerging as municipalities integrate water buffering, infiltration, and reuse into planning frameworks. Regulation therefore both limits certain circular solutions and simultaneously increases the urgency to adopt others.

4.2.5 Execution and maintenance

Finally, practical execution and maintenance challenges limits but needs to be in place for implementation. Systems such as Hydraloop require additional piping, separate drainage pipes, and regular maintenance. More experimental technologies, such as recycling showers, are maintenance-intensive and was mentioned I the interview by site managers and developer to face resistance from contractors, housing associations, and residents.

Health concerns also play a role in recycling water. Potential health risks associated with household water reuse, highlighting the need for strict monitoring and management (Vewin, 2022). Without clear operational guidelines, many organizations are hesitant to adopt systems that introduce new responsibilities and liabilities. Although some systems came forward in the interviews to have already proven to fulfil the different regulations.

Moreover, coordination between actors is often fragmented. Ministries, water authorities, municipalities, and housing associations operate under separate mandates and budgets, leading to misalignment and slow implementation (Czischke et al., 2025).

Execution and maintenance challenges therefore reinforce the preference for simpler, low-risk solutions and are barriers for recycling systems of rainwater or greywater.

4.2.6 Conclusion

This chapter shows that (circular) water-saving solutions in dutch high-rise projects are shaped by five key drivers and barriers. The most important driver and barriers are: rules and regulation, financial feasibility and knowledge and awareness. The first barrier to overcome is the low awareness: many people in the sector don't realise how large the water impact of materials is. Even though dutch water utilities warn that long-term supply cannot be guaranteed (Van Leerdam et al., 2023).This makes water a new constraint for new housing plans like the net congestion (Drinkwaterplatform, 2025).

At the same time, municipal requirements are becoming a strong driver. Cities like The Hague now link water buffering and reuse directly to the environmental permit, which pushes developers to act. However, financial feasibility remains a major obstacle. Systems like greywater reuse or cascading irrigation are expensive, have long payback times, and increase service costs. As several interviewees noted, potable water is simply too cheap to make these systems financially attractive (Appendix 4). Regulation both helps and blocks progress. Belgium shows that mandatory measures can sharply reduce water use (Armeni, 2008), but in The Netherlands, the Drinkwaterbesluit still restricts using rainwater or treated greywater indoors (Vewin, 2022). Meanwhile, The Netherlands risks missing its 2027 KRW targets, which may lead to stricter permitting and more pressure on developers (Groothuijse & Van Rijswijck, 2023).

Finally, execution and maintenance challenges make many organisations hesitant. Extra piping, monitoring, and health-risk responsibilities create practical barriers, especially when governance between ministries, water authorities, and municipalities is fragmented (Czischke et al., 2025). In short, the technology for circular water systems already exists but awareness, rules, costs, and practical challenges still determine whether these solutions are actually implemented in Dutch high-rise projects.

4.3 Implementation plan

The Netherlands faces a growing mismatch between potable water availability and water demand, intensified by climate change, rapid urbanization and increasing pressure on freshwater systems (chapter 2.1.1.). This research has shown that the construction sector plays a significant role in this challenge: both material production and the operational phase of residential high-rise buildings require substantial volumes of freshwater (chapter 4.1). As a result, the sector is increasingly expected to contribute to reducing potable water demand and improving rainwater infiltration in response to heavier rainfall events.

With the role of water now clarified in terms of quantity, time and impact, it becomes possible to identify where meaningful reductions can be achieved. The interviews and academic literature revealed a set of drivers and barriers that influence whether (circular) water-saving solutions are adopted in practice. These insights form the basis for determining how developing contractors can act. This chapter addresses the third sub-question: Which (circular) water-saving solutions can developing contractors implement within their projects?

The focus on projects, rather than the organisation as a whole, is deliberate. Projects function as temporary organizations that introduce new practices, tools and routines, which can subsequently influence the permanent organization (Silvius et al., 2012). In other words, implementation begins in projects, where design choices, procurement decisions and collaboration with suppliers directly shape water use.

This chapter therefore presents an implementation plan that translates the research findings into actions for project teams. It first outlines solutions for the material production/selection phase, followed by solutions for the operational phase. It then introduces three overarching implementation measures that apply across both phases, and concludes with broader organisational considerations, while keeping the primary focus on project-level implementation.

4.3.1 Material production/selection

This research analysed the role of water during material production and the operational phase of a building. For the material production, approximately 28% of the water consumption is determined, taking into account that the life expectancy of a building is set to 75 years for the operational phase. The timing on when to choose the type of window frames in aluminum or other materials, the construction in concrete and the outside façade cladding to be with bricks or other materials is decide all pretty early on in the process and gives implications for many aspects further along the project execution.

The impact on fresh water use is quite limited with concrete production being the one where they use fresh water with the quality of potable water because of the high quality requirements needed for the concrete production. However the total water quantity and the contamination are most present with the production of aluminum. Across all three materials, the water used is predominantly freshwater rather than brackish or even salt water, which is significant given the increasing scarcity of freshwater resources globally.

For developing contractors, the possibilities for (circular) water-saving solutions in material production are limited, because the production processes themselves lie outside their direct control. Solutions which are possible can be divided into four main categories:

- The type of material
- The making
- Influencing of the industry
- Awareness

The influencing of the industry and the awareness implementation is explained in chapter 4.3.4. and 4.3.5. For both the material production and the operational phase. The other two are elaborated below.

THE TYPE OF MATERIAL

The making of the products is something that is in the hands of the supplier the materials are purchased from. A key method for targeting water consumption reductions is to change policies surrounding water consumption for industrial material production (Miller et al., 2018). However developing contractors are not the ones in charge of making the policies concerning industrial production for materials. One possibility would be that developing contractors or other parties who buy materials, change the questions that are asked. Just like with CO_2; how much CO_2 is executed during the making of the product has become important to register, track and report the CO_2 levels within a project. This same standard could be applied for water use during production. This information creates awareness on what the impact of the material used is.

In chapter 4.1, the water footprint of the project and three key materials was calculated. Other studies, such as Crawford and Pullen, also show that materials differ strongly in how much water they require. This can be shown in the "material pyramid," in Figure 16 with high-water materials at the top and low-water materials at the bottom. These values are relative, but gives a quick overview and for some materials the expected water use in the Netherlands for 2030 (Arnoldussen et al., 2026) is included to illustrate which materials are most water-intensive

Although some materials have a high water footprint at the production stage, they may offer substantial benefits later in the life cycle. Aluminium, for example, has a high initial water demand but strong reuse and recycling potential, especially when designed for disassembly. In contrast, PVC window frames typically end up in landfill or incineration, offering limited circular value (Asif et al., 2005).

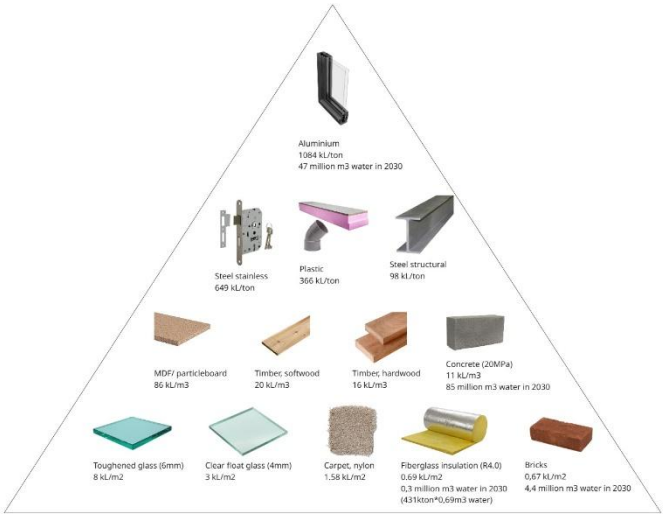

Figure 16 - Material pyramide (based on the research of crawford and pullen)

THE MAKING

Although the developing contractor is not responsible for the creation of the materials they use during the building process, you can still ask them to provide insight into the amount of water used for the materials they source and during their own construction process.

Wet versus dry process: Interviews with two different urban concrete recycling factories highlight that the method of recycling concrete strongly affects water demand.

Factory 1 uses a dry separation process, which avoids the large volumes of water normally needed to wash aggregates. Because of part of the cement in demolition concrete has not fully reacted. If water is added during recycling, this cement could re-activate instead of being recovered. Their dry process allows them to extract and reuse this cement, reducing both water use and the need for new cement. This aligns with academic findings that dry recycling significantly lowers the water footprint of concrete production

Factory 2, uses a wet cleaning process, which requires substantial water input. Although they recycle this water as much as possible and is mainly rainwater or industrial, fresh is still needed.

For developing contractors, this means that the choice of concrete supplier matters. When both factories are available, selecting Factory 1 can reduce the project's water footprint, provided that price, availability and structural requirements allow it.

Water-reducing additives: Several studies and interviews show that concrete mixes can be optimised to reduce both cement and water demand. Research from India estimates that using water-reducing admixtures can save 2 m^3 of water per ton of cement, resulting in millions of litres saved at national scale (Sakhardande et al., 2025).Cement can be partially replaced with fly ash, slag or limestone fillers, which reduces water demand and improves workability (Satthya, 2023).

A good example was reflected upon during the interviews with the site manager that he worked together with the structural engineer to lower the cement content without compromising strength. This reduced both CO_2 emissions and the water needed for mixing.

Alternative curing methods: The interview with the coordinator for sustainable solutions showed that adding industrial residual streams to clay reduces the water needed during shaping and shortens drying time. This allows bricks to be fired at temperatures up to 200°C lower, reducing both water and energy use while using residual streams too. Literature confirms that optimising clay composition can significantly reduce water and energy demand in brick production.

The material production phase, responsible for one third of the total water use in the case study. Although developing contractors cannot change the material production process directly, they can influence the water demand for the project by:

- selecting materials with lower water footprints and looking at reuse potential
- choosing suppliers with lower-water production methods

- requesting water-use data
- encouraging mix optimization

This shows that meaningful reductions are possible, even with limited direct control.

4.3.2 Operational phase

The issue we face, and which is receiving increasing attention, is the growing shortage of potable water, compounded by climate change that intensifies both water scarcity and limited access to water (chapter 2.1.1.)

The possibilities during the operational phase are quite broad and definitely not all applicable for the focus on the high-rise buildings. High-rise buildings, such as the Lomanlaan case project, have a relatively compact layout when it comes to installations. This point of view was highlighted by one of the head site managers of the company. He works on a project similar to Lomanlaan and explained that in the space within as well as beneath the floor of such a project you have to deal with all of the installations that will go in and out the building, the big foundation slaps and the limited space that these create.

Recent research done in The Netherlands with 55 public and private parties on how (new) neighborhoods can be smart and more efficient. They worked together on bringing recent solutions into one comprehensive list called ‘’menukaart’’ translated to a menu from a restaurant (Bouwtafel waterzuinige wijken, 2026). This is a great overview of what possibilities are available with some extra information for each solution. Other research like Tucci et al. (2024) researched source control (reducing & recycling), water reception (infiltration) and water diversion (infiltration), Wang & Hao (2015) also looked for solutions applicable for high-rise buildings on the water saving (reducing) and resource utilization (recycling) and rainwater runoff (infiltration).

When overlooking all of these possibilities of different research and from interviews together, four major categories are found. These four being; recycling, reducing, infiltration and a part of awareness that will influence the water use during the operational phase. The part of awareness is talked about in more detail in chapter 4.3.5. as it not only touches upon the material production or the operational phase but moves beyond those phases.

RECYCLING

During the operational phase of a building, the main water types involved are blue water (potable water or collected rainwater) and grey and black water that results after its blue water is used. These water flows are present in and around the building and form the basis for most recycling strategies.

When looking at what water to reuse the solutions are mostly about recycling the rainwater or the grey water (Bouwtafel waterzuinige wijken, 2026). Some regions already require this: for example in Flanders (Belgium) it is mandatory to place a rainwater basin for new build, repair or an extension of an existing building and used where potable water is not necessary (Vlaamse Codex, 2023).

Recycling in the form of reusing the grey water needs to be noted that this is only effective for prevention to limiting the amount of water that is run down the drain (Tucci et al., 2024). However this recycling of

greywater has proven to reduce 21% of potable water (Marinoski et al., 2018). Reviewed possibilities for recycling the greywater for high rise buildings are;

- The Moving Bed Biofilm Reactor MBBR systems (Hydraloop)
- Recycling shower

The Moving Bed Biofilm Reactor MBBR systems (Hydraloop): A supplier of such a MBBR system is Hydraloop. The Hydraloop MBBR systems treat greywater from showers, baths, and washing machines to a quality suitable for non-potable usage such as toilet flushing, irrigation, and laundry. Their integration can significantly reduce potable water demand and improve the long-term resilience of housing projects. The Hydroloop expert highlighted that:

''for the use of the shower we use 46,2 liter per day per person, the toilet and washing machine use a little less but around the same and align just fine with each other''
-10. Regional sales manager greywater recycling

This indicates that with recycling the water from the shower you can use this perfectly for the use of the toilet and washing machine without needing extra water. The system cascade is a decentralized, modular system designed for individual dwellings or multi-unit buildings. For high-rise buildings this would be financially and space efficiently more interesting to combine the water recycling into one system. It treats greywater through a combination of sedimentation, flotation, foam fractionation, aerobic bioreactors and UV disinfection, without relying on traditional membrane filters. This design that requires no filter reduces maintenance needs and ensures stable performance over time. Once treated, the disinfected water is stored and reused for toilets, gardens, laundry, or even pool top-ups. When the 21% reduction is applied to the case project Lomanlaan this reduction is;

$$20.000\ m^3/year \times 0{,}21\ reduction = 4.200\ m^3/year$$

According to the 'menukaart', potable water use offers one of the greatest reduction opportunities, especially since showers are used almost daily in most households. The impact of the system is great both financially (chapter 4.2.3.) as for the implications of the system within the building and its maintenance (chapter 4.2.5.). Although the application of this system for high-rise buildings is possible, it's a difficult business case to make financially highlights the site manager. For implementation within the plans it is crucial that this is done early on in the process for good execution.

Recycling shower: a recycling showers where the shower significantly reduces the amount of potable water by reusing shower water. Instead of sending used shower water directly to the drain, the system filters and recirculates it, requiring only two to three litres of fresh water per minute to maintain hygiene and compensate for losses

From a technical perspective, recycling showers are relatively easy to integrate. They require only a connection to water, electricity and a drain, minimal floor preparation and therefore creates financial feasibility (Marinoski et al., 2018). Easy installation and minimal adjustments are critical as they can become pretty expansive when extra pipes are needed (chapter 4.2.3.) as with the case of the Hydraloop mentioned above. A positive outcome for execution but the maintenance and no feeling of urgency remains a barrier for application. Interviews confirm this hesitation:

''large housing associations are unlikely to adopt such systems quickly due to maintenance and low perceived urgency''
– 11. Site manager residential high rise project

Manufacturer estimates suggest savings of around €1,200/year with payback periods of 5–6 years in the Netherlands and 3–5 years in Belgium, but these figures are not independently validated and depend heavily on user behavior. Research should be made on the real savings of the system. Overall, recycling showers are promising but experimental: theoretically strong, practically simple, but lacking robust evidence and facing adoption barriers for investors and housing associations.

To conclude, as mentioned earlier for the application of water saving solutions much of the barriers as mentioned in chapter 4.2 are present for the application of recycling solutions. Even though research and practice is showing great reduction with the application of reusing greywater the application of these kind of systems are hard to implement at this moment in time. Promising solutions like water bags used for low rise buildings beneath the building are not applicable for high rise building as they will need to be greater to gather the supply. To create suitable water tanks it will be needed to put underneath in the ground or systems like Hydraloop could be applied but creates greater investment costs and good coordination upfront for within the design due to the extra pipes needed. However when we want to make a change and prepare ourself for possible water shortage solutions like this are great to do and are possible solutions for residential high-rise buildings.

REDUCING

Recycling the (grey)water again within the project is great but tackling the problem at the source through water efficient appliances is simple and effective. For developing contractors reducing the water demand during the operational phase can be done in multiple ways. Through recycling systems as mentioned in the chapter above, by creating awareness by its residents or by placing water efficient appliances. The awareness part is talked about in chapter 4.3.5. because it is not only applicable for the operational phase but moves beyond that.

Unlike recycling systems for grey or blue water, efficient appliances require no additional piping most of the time, no tanks or treatment units thus making them far easier to implement within the spatial and organisational constraints of high-rise buildings for reducing the water demand. Replacing conventional fixtures with high-efficiency devices could reduce water consumption by up to 50% in single-family houses and 42% in multi-family buildings, without requiring changes to existing water distribution networks (Amado & Barroso, 2013). The reviewed possibilities for reducing the water demand for high-rise buildings by efficient appliances are;

- Water efficient shower head
- Water efficient toilet flush system

Water efficient shower head: Showers use the largest amount of water in households (30–40% of total use), so reducing this water use has a direct and predictable impact on total consumption during the operational phase(Beal et al., 2013; CBS, 2023) Unlike recycling systems, which require behavioral acceptance and extra maintenance, efficient showerheads deliver savings regardless of user awareness (Wang & Hao, 2015). However, their impact is still constrained by behavior, a long showers still remains a long shower. It was highlighted that some residents, may perceive reduced comfort, especially for high-end appartements this can limit acceptance.

Water-efficient showerheads reduce water use and have different levels as this research is for Dutch standards the NEN norm for flow rate classes is used. These levels or classes is how they are called in the NEN norm range from the least efficient shower heads (D) that use 30–38 L/min to the most efficient shower head (ZZ) that uses 1,5– 7,2 L/min (NEN, 2008).

For the contractor's own buyer-selection process: residents can go to the warehouse (showroom for sanitair and kitchen) to choose from standard fixture packages levels 1, 2 or 3. The level of the package is decided upfront with the developer but can be upgraded or downgraded with fixtures they choose but has financial consequences the buyer has to pay. Within package 1 and 2 the two types of shower heads you can choose from use 9 l/min. Which is not the most efficient but high up the level. However as also reflected in the interview is that for the high end apartments where the more expensive package 3 is most likely to be chosen. For this category a shower heads usually use 13 to 16,4 l/min. Most of the selection possible in The Warehouse are great shower heads in terms of efficiency. However, integrating more efficient options into these packages is the next step forward and does not require changes to the building design.

Water efficient toilet flush system: Toilets account for roughly 24% of household water use in the Netherlands (CBS, 2023), making them a high-impact target for reduction. Just like with water efficient shower heads a water efficient toilet does not need behavioral acceptance and extra maintenance (Wang & Hao, 2015). Modern 3/6 L dual-flush toilets and ultra-low-flush systems like OptimFlush toilet can reduce toilet water use by up to 60% compared to older 9 to 12 L models. The toilets used now in the warehouse for the buyer-selection process toilets use between 4,5 to 6 liter per flush. Looking at the dutch NEN-EN norm 997 (NEN, 2018), this is already in the lower classes for a toilet flush. A reduction of 4,6 liter per flush which is a reduction of 23% for toilet use. For the application for the Lomanlaan this is:

30,2 L toilet flushing per day x 0,4 % water reduction = 12 L reduction per day per person

On a yearly basis this results in a reduction of:

(12L reduction per day x 365) * 452 = 1.980 m3 per year for project Lomanlaan (10%)

A reduction of 10% on the total water use per year could be achieved by implementing this type of toilets. Efficient toilets also complement other measures and that by combining efficient fixtures with greywater reuse can reduce total potable water demand by up to 42.9%, demonstrating that fixture efficiency strengthens the performance of more advanced systems (Marinoski et al., 2018).The

adoption of this toilet the SAT OptimFlush from Biocompact has made its first projects in The Netherlands with apartments where they started 2 years but are placed in Amerika and asia. The toilet is available from € 995 excl btw on the website for individual customers so possible reduction could be in place. This toilet however does not need a toilet cistern (inbouwreservoir).

For developing contractors, water-efficient toilets are a high-impact, low-complexity intervention that fits seamlessly into high-rise projects and offers guaranteed reductions without additional design or maintenance burdens.

In conclusion, the options analyzed for reducing the water demand for the shower and toilet showed promising options. The installation of both options requires limited to no alterations compared to a normal toilet or shower head.

INFILTRATEN

Infiltration plays a crucial role in managing water in dense urban environments, especially as cities face both water scarcity and extreme rainfall. By keeping the water locally and slowly letting it into the sewage system takes the pressure off the sewage systems. Cities like Stockholm are great examples and are called ''sponge'' cities. For high-rise buildings, where ground-level space is limited, infiltration requires compact systems that temporarily store water and release it slowly into the environment (Monachese et al., 2025). Reviewed possibilities for infiltration of rainwater for high-rise buildings are:

- Cascade system
- SlowFlow tile

Cascade system: The cascade system is an infiltration solution that distributes rainwater across multiple building levels rather than relying solely on the top roof of storing the water. The name cascade is a process, event or sequence where things like water flows in the next stage. Its name comes originally from the french word for waterfall (Britannica, 2026). The use of buffering water on several levels, increases the effective surface area available for retention, a key advantage for high-rise buildings with limited footprint.

By the cross section of residential high-rise project Link in the Binck in Figure 17 you see the top roof that holds and transports water to the green pockets on multiple levels where the water is used for watering the plants, stored and when its full flows to the sewage. In chapter 4.2.2. the municipal requirements were highlighted that addressed requirements for water infiltration. This buffers the water and slowly lets the water flow vertically down, the system meets surface-based requirements for water retention even on small building plots.

Figure 17 - Cross section Linck in the Binck project (ERA Contour project drawing)

''..by deploying this cascade system and the created surface area...you then meet the surface requirements.''
– 11. Site manager high-rise residential building

The principle aligns with research showing that multi-stage drainage systems reduce peak runoff and support gradual infiltration by slowing down the movement of water through the building envelope (Zhang et al., 2025). The cascade system therefore functions as a hybrid solution: it stores water and delays discharge, while also providing opportunities for irrigation the greenery without relying on potable water.

Drainage slow flow: Drainage slow-flow systems are designed to temporarily withhold rainwater on flat roofs and release it gradually. Products such as the AGS Slow Flow ring use a weighted aluminum ring with small openings placed around the roof drain. This allows the roof to act as a temporary water basin, slowing down the outflow during heavy rainfall events.

The SlowFlow tile is used among almost all of the projects of the project by the developing contractor. It is an easy applicable solution, no extra adjustments are needed, withholds leaves from falling into the sewage pipes and works well in combination with green roofs like moss for watering. The site manager speaks positive about previous experiences:

''It is actually better to apply it than not..''
– 11. Site Manager high-rise residential project

Infiltration solutions complement recycling and reduction strategies by restoring part of the natural water cycle within dense urban areas. The cascade system uses the vertical structure of high-rise buildings to create additional buffering capacity, while slow-flow drainage tiles reduce peak loads and support gradual infiltration. Together, these systems help manage extreme rainfall, reduce pressure on sewer networks, and contribute to a more climate-resilient built environment.

For high-rise developments, infiltration is therefore not only feasible but essential, an intervention with high impact on long-term water management.

4.3.3 Influencing the industry

Developing contractors occupy a central coordinating position in construction projects, connecting many stakeholders like the clients, designers, suppliers, municipalities, and subcontractors. In Figure 18 you can see the main stakeholders for a project which is developed and realised by the developing contractor.

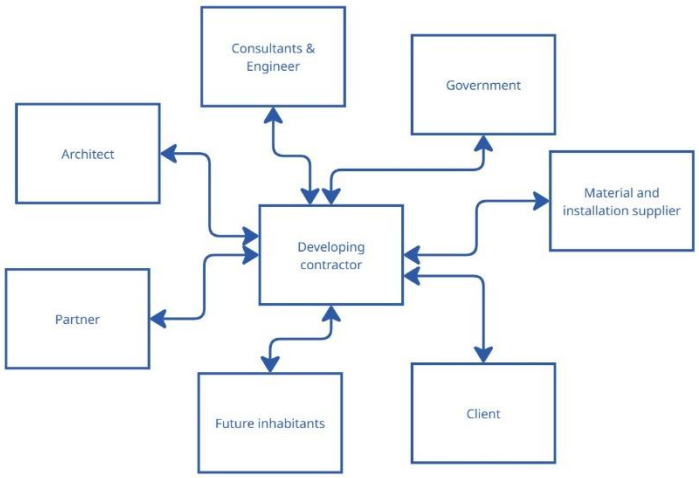

Figure 18 - Central position developing contractor with stakeholders (own graph)

Because they sit at the middle of these relationships, they can influence how other stakeholders prioritise and adopt water-saving and sustainability solutions. In return, this is also done the other way around by governmental parties through regulations for instance. This influence is well-documented in construction-supply-chain research, which shows that contractors can accelerate sustainability transitions. Influencing procurement choices is found to be a critical way that directly influences the construction project (Hettiarachchi et al., 2025). Besides procurement initiating collaboration to work towards shared goals, and embedding these environmental criteria into project delivery enhances shared accountability and support (Hettiarachchi et al., 2025; Jean, 2024)

For example with the concrete suppliers it was highlighted that the concrete suppliers, with whom the developing contractor works often, are talking nowadays about the CO^2 reductions that they can make so that they can both benefit from this. The CO^2 reduction process has great lessons that can be learned from and shows that things are looked at when the urgency is present and the need from regulation is applied. So a mix between the drivers knowledge and awareness and rules and regulations that enabled this change. This conversation started by gathering the insights with how much CO^2 is present.

Figure 19 - Kansenkaart renovation project (ERA Contour visualisation)

As previously mentioned with the material production solution, it should be asked how much water is present. It made both parties critical and curious on what can be done about the huge CO^2 emissions of concrete and how they could lower this. By starting this conversation and jointly think about solutions, these solutions are being realized and both parties and the planet benefit from this. The MPG-score is lower, there is less CO^2 emission and the companies have work to execute, showing that meaningful progress does not always require full system change from the start.

Another example of effective influence is found in neighborhood renovation projects. During the kick-off meeting, the developing contractor brings together all parties, including the investor, to discuss the project scope. The process begins with collecting everyone's input on post-its and using kanskaarten for inspiration shown in Figure 19. These cards are available for three building types: gallery-access flats (galerijflats), apartment buildings with communal entrances (portiekflats), and terraced or detached houses. This simple but structured method helps align stakeholders and encourages the adoption of sustainability measures. This approach could be expanded with the findings of this research to include (circular) water-saving solutions for both renovation and new-build high-rise projects.

Overall, developing contractors have significant influence because of their central position in the construction process. By using procurement, collaboration, and structured decision-making tools, they can actively shape how sustainability and water-saving solutions are adopted across the chain. The examples in this chapter show that influence often begins with small, concrete steps, such as creating insight, starting conversations, or adjusting routines, which can ultimately lead to broader industry change.

4.3.4 Small wins

Within the implementation strategy of developing contractors, small wins are proven to be an effective way for the implementation of (circular) water-saving strategies in high-rise residential development projects. The concept of small wins was highlighted during one of the interviews and refers to interventions that require limited effort or investment but can trigger broader organisational change over time (Van Hal, 2025;Silvius et al., 2012; appendix 4). Instead of focusing only on large, complex innovations which can feel out of reach, small wins allow project teams to start acting immediately and to gradually build experience and support for further development within the organisation.

Within the context of developing contractors, small wins are particularly relevant because projects function as temporary organisations within a limited time and budget (Silvius et al., 2012). A small win is effective when it requires other actors like designers, suppliers, installers, or internal teams, to modify their standard practices. This ripple effect builds momentum and reduces resistance, because the organisation experiences change through practice rather than policy alone.

An example emerging from the interviews is the potential small win of creating space for, or when financially feasible, pre-installing dual piping for future greywater reuse. Although the interview with the site manager suggests this may not always be realistic, its actual feasibility must be examined further before drawing conclusions. What makes this intervention a *small win* in the sense of Van Hal is not its size, but its system-shifting effect. Even without installing the recycling system itself, the presence of dual piping forces multiple organisational adjustments: design teams must coordinate differently, installers must adapt their routines, suppliers must provide compatible components, and the building becomes technically prepared for circular water use. In this way, a seemingly modest intervention triggers a broader organisational shift, demonstrating how small wins can initiate fundamental change despite the financial, technical, and regulatory barriers that typically hinder large-scale water system innovations (chapter 4.2; Riazi et al., 2023).

The research reveals additional opportunities for small wins that create similar ripple effects:

- Water-saving fixtures: While simple, their integration requires coordination between procurement, installation, and commissioning teams. It also changes performance expectations for residents and maintenance staff. This could even give the possibilities to let buyers choose extra water-saving fixtures like a recycling shower. Requiring more coordination and execution steps.
- Rainwater buffering on roofs: Through interventions like the SlowFlow tiles which should always be integrated with a flat rood structural water buffering will be integrated. More advanced systems like cascade systems are the next step and influences structural design, drainage planning, and collaboration with maintenance of these systems, thereby affecting multiple disciplines and project structure.
- Introducing water-impact checklists in early design phases: Lists with possible (circular) water saving solutions for the project. Like the existing green list for CO2 reduction adapted to water. A small procedural change that forces architects, advisors, and developers to consider water earlier, shifting the decision-making culture and project process steps with this optimization steps through the checklist.

- Requesting water-related data from suppliers: This administrative action compels suppliers to rethink transparency, documentation, and product development, influencing the wider supply chain.
- Internal communication of water-related insights: Sharing project data or pilot results creates new expectations and norms within the organisation, gradually shifting the internal culture. Creating goals for water-savings makes this concrete.

These small wins work because they change how people normally do things, shift what they expect, and gradually create new standard practices. They demonstrate that circular water strategies are not optional add-ons but integrated components of development practice. However, their long-term impact depends on consistent reinforcement. Small wins must be connected, communicated, and embedded into organizational processes to prevent them from remaining isolated successes and stay within the pilot phase.

By strategically selecting small wins that trigger system-wide adjustments, developing contractors can build momentum toward circular water use while maintaining feasibility within current project structures. This approach aligns with Van Hal's insight that systemic change begins with small, visible actions that make the old way of working impossible to maintain.

4.3.5 Awareness

Awareness is an important starting point for implementing (circular) water-saving solutions (Riazi et al., 2023). The findings of this research show that, compared to CO_2, water remains a relatively invisible topic in both the construction sector and within project decision-making processes. This lack of awareness limits the willingness of stakeholders to invest in water-saving measures and reduces the likelihood that water is considered during early design stages and later on executed within the project.

Literature on behavioural change and resource use emphasizes that awareness is a critical precondition for action (Kollmuss & Agyeman, 2002;Alsanad, 2015)When stakeholders do not understand the scale or relevance of water use, they are unlikely to prioritise it. This is particularly evident in construction projects, where decision-making is strongly influenced by cost, regulations, and established routines, and where new topics require visibility or regulations to gain attention. For project implementation, awareness can be created at different levels.

''It is also a matter of awareness. That is what it is all about. That awareness stemming from what your research is. That is not really alive yet.''
– 11. Site manager residential high-rise project

For the implementation it is therefore important to first create this awareness. In the case of the developing contractors, awareness should be approached as a practical implementation strategy rather than an abstract concept. Awareness can be built directly through project requirements, but also indirectly by shaping the culture inside the organization which is needed for people on the project to

Figure 20 - Transformation story ERA Contour (own picture)

understand what is the need for these implementations. A good example is ERA Contour's internal veranderverhaal ("change story"), which is visible throughout the office (Figure 20). It reminds employees that their daily decisions contribute to the company's goal of becoming Paris Proof by 2030. The message is simple: nature does not send invoices, but we still carry responsibility and we give nature space again by making greenery, water, and life part of what we build.

This kind of internal storytelling helps make sustainability concrete and personal. It shows that awareness is not only about knowing the numbers, but about creating a shared mindset that encourages people to act. For water, a similar approach is needed. When people understand the scale of water use in materials and the risks of future shortages, they are more likely to support and implement water-saving solutions in projects.

Within the project organisation itself, awareness can be strengthened through internal initiatives such as sustainability programmes, workshops, or "Dosis duurzaam" paper. For this research the special edition for water is introduced and can be found in appendix 6. The focus for this edition was to create awareness around the topic water but already give a hint for what can be done for building and living with less H_20. It summarizes key findings and numbers to create this awareness. The poster was discussed within a small group and immediately created a lot of questions for curiosity and shock even. It showed that these already known initiatives help to translate abstract sustainability goals into understandable and applicable findings that can be put into project execution.

Figure 21 - Awareness creation on flush button (own picture)

Similar approaches have been successfully applied for CO_2 reduction, where internal programmes and teams like the ''green rebels'' have increased attention and knowledge within the organisation. Not from the top down but from different levels and expertise.

In addition, developing contractors can play a key role in raising awareness within the supply chain. By actively asking suppliers about the water use of materials, similar to how CO_2 emissions are discussed through MPG calculations, contractors can stimulate transparency and innovation. Supply chain research shows that client demand is a strong driver for sustainability improvements in construction (Alghamdi, 2025)

At the level of residents, simple interventions can already have an effect. An example is seen in Figure 21. Where a visual reminder on the toilet shows users how much water is used when flushing the toilet. Such low-cost interventions make water consumption concrete and can influence behaviour without requiring major investments. Providing feedback and visual reminders can lead to measurable reductions in water use (Beal et al., 2013). A more advanced form of awareness is the use of smart metering systems. These systems provide real-time insights into water consumption and can detect leaks or abnormal usage patterns. Although currently more common in large building portfolios like hotels or whole building complexes, they can also be applied in residential projects. Feedback and insights from smart meters can

reduce household water use by increasing user awareness and enabling behavioural adjustments (Interview 7 in Appendix 4; Willis et al., 2013).

The strength of awareness as a strategy lies in its low threshold and broad applicability. It does not require major investments or regulatory changes and can be implemented in every project phase. However, awareness alone is not sufficient. Its effectiveness increases when it is directly linked to concrete actions, such as small wins or pilot projects.

In conclusion, awareness is not only the first step towards reducing water use, but also a continuous process that supports decision-making, stimulates innovation, and aligns stakeholders. By combining simple communication tools, data-driven insights, and active engagement with project teams and suppliers, developing contractors can create a foundation for implementing circular water strategies in practice

4.3.6 Conclusion

Chapter 4.3 shows that developing contractors actually have more room to act on (circular) water-saving solutions than it may seem at first. While they cannot change industrial production processes themselves, they can influence outcomes through early material choices, smarter procurement questions, and by creating awareness and when possible selecting suppliers who use lower-water demand for their production methods. Even small shifts, such as asking for water-use data alongside CO_2 data, can start changing routines in the supply chain. With great process for CO2 showing what this can create.

For the operational phase, the range of possible solutions is much broader and in the hand of the developing contractor.

High-rise buildings have spatial and technical limits, but there is still a wide range of solutions that fit well. Greywater recycling systems like Hydraloop can reduce potable water demand by around 21% (Marinoski et al., 2018), and recycling showers offer additional potential. It should however be noted that they both face financial and maintenance barriers. In contrast, reducing water use through efficient appliances such as efficient showerheads and dual-flush toilets, is simple, cheap, and easy to integrate into high-rise buildings. These measures offer predictable savings without extra piping or complex systems (Beal et al., 2013; Wang & Hao, 2015)

Infiltration solutions also offer clear opportunities. Cascade systems and SlowFlow tiles already work well in high-rise buildings, dense urban environments and help meet municipal requirements while reducing pressure on sewer systems (Zhang et al., 2025).

Beyond the technical options, it highlights that developing contractors can play a connecting and influencing role. Because they sit at the centre of the project network, they can bring suppliers, designers, and municipalities together around water-saving goals (Hettiarachchi et al., 2025). Besides market parties they bring influence on the residents too which have a large impact in the operational water demand. Small wins through trying a new fixture, adjusting a concrete mix, or asking new questions and help build momentum and make water a normal part of project conversations.

Overall, the implementation plan shows that meaningful progress is possible right now. Some solutions require long-term regulatory or financial changes, but many practical steps, especially early material choices, efficient fixtures, and infiltration measures can already be integrated into high-rise projects today. With growing awareness and increasing pressure on water availability, these early steps can help prepare the built environment for a future where water plays a much larger role in design and development.

5. Discussion

This research set out to clarify the role of water in high-rise residential buildings across two dimensions: the quantity, timing, and impact of water use during material production and the operational phase, and the drivers and barriers that shape whether circular water-saving solutions are actually implemented. By combining quantitative life-cycle assessment with qualitative interview data, the study provides a multi-dimensional perspective that existing research has typically treated separately. The clarification of the role of water enables the implementation plan to give the developing contractor concrete direction on implementing (circular) water-saving solutions, beginning with a strong focus on awareness.

Several overarching observations emerge from the findings. First, water-usage in residential development is both large and largely invisible. The finding that embodied water in construction materials equals roughly 29 years of operational water use means that approximately one-third of a building's total lifecycle water demand is already determined before the first resident moves in. This has an important implication: waiting until the operational phase to address water use misses a substantial share of the total footprint. This finding is consistent with Crawford & Pullen (2011), who demonstrated that indirect water dominates the total demand of an Australian residential building. However, a critical difference must be noted: the study included food consumption in their indirect water calculation, which produced a much lower share for construction materials than found here. When food is excluded, the relative importance of construction materials increases considerably, placing the present findings closer to the range reported by Han et al. (2016) for a commercial building in Beijing, where materials accounted for over 75% of the total water footprint.

Second, water operates across multiple scales simultaneously. Decisions made at the building level, the choice of window frames, the concrete mix design, or the toilet specification, all have consequences that extend to regional water availability when its applied on a larger scale. This multi-scale characteristic aligns with the framework of Tjallinghii (1996), who argued that water flows, areas, and actors are always interconnected. This study provides empirical confirmation of this theoretical position: the Lomanlaan case shows that a single building's material choices affect water demand at the factory location, the regional water system, and the national potable water supply. What the literature has not sufficiently addressed is how this multi-scale effect interacts with the position of the developing contractor and what conclusions society, the developing contractor or someone else should make with the conclusion on the role of water for a building, its materials and operational use. This discussion shows that the contractor’s influence extends beyond the project boundary, and that water-aware decision-making requires looking across scales, not only within the building itself.

Third, the sector is currently at a point where awareness, financial feasibility and regulation reinforce each other in a way that slows progress. It is a continuous cycle where low awareness, high financial investments with low return and inadequate regulations keep recurring and hold back progress. Breaking this cycle requires understanding not only what the technical solutions are, but how they can gain grip within project structures. The five concluded drivers and barriers identified here, overlap significantly with Alsanad (2015), who found limited awareness and weak policy support as primary barriers to sustainable construction in Kuwait. However, the Kuwaiti context differs substantially in terms of water scarcity

intensity and institutional capacity, which means that the same barriers may require different solutions in the Dutch institutional context. Riazi et al. (2023) emphasised that governance complexity increases as water systems become more circular, a finding confirmed by the fragmentation between Dutch ministries, water authorities, and municipalities observed in this study. Morseletto et al. (2022) argued that regulation can create a forced pathway toward circular practices, a mechanism confirmed by the interviews where regulation was cited as both the most effective enabler and the most restrictive barrier. The Drinkwaterbesluit, which currently restricts indoor use of rainwater and treated greywater, illustrates that regulation can simultaneously push and block circular water progress.

Fourth, the study reveals a structural parallel between the current position of water and the historical trajectory of CO_2 in the Dutch construction sector. CO_2 was once equally invisible in procurement and design decisions. The sector-wide shift occurred through a predictable sequence: research established the magnitude of the problem, frontrunner companies began asking suppliers for data, regulation created a level playing field, and the topic became embedded in standard practice. Water appears to be at the beginning of a similar trajectory, but with an important difference. Unlike CO_2, which is a global externality, water scarcity is locally experienced and regionally specific (Boulay et al., 2018; Mekonnen & Hoekstra, 2016) A shortage in Twente does not directly affect a developer in Rotterdam. This means that the regulatory and market signals for water will likely emerge unevenly across regions, driven by local water stress rather than by a uniform national policy.

What this research adds is the integration of these dimensions within a single case study, connecting life-cycle water data with organisational decision-making in a specific project context. The Q-T-I framework provides a replicable method that other researchers and practitioners could apply to different building typologies or regions. This is no easy process, but gathering the insights and building the awareness that change is needed is the first step to which this research contributes.

5.1 Contribution

This research makes three main contributions. First, it provides a structured, multi-dimensional assessment of water use in high-rise residential development that integrates virtual water in material production with operational water demand. Both dimensions that are typically treated separately in the literature. Second, it identifies the five drivers and barriers that determine whether circular water-saving solutions are implemented in practice. Third, it clarifies the developing contractor's position as a central but constrained actor, demonstrating that while their influence on industrial production is limited, their leverage in early design, procurement, and operational choices is substantial. By applying the small wins concept to water, the research offers a practical theory of change that connects immediate feasible actions to longer-term circular ambitions that realises project implementation to influence the company itself.

5.2 Limitations

Several limitations should be acknowledged. The quantitative analysis relies on average water-intensity values from literature and EPD data, which introduces uncertainty. Reported values vary significantly depending on production methods, regional conditions, and calculation methodologies. The use of the AWARE factor in some EPDs adjusts for regional water scarcity rather than reflecting actual withdrawal, which complicates comparison between materials (Boulay et al., 2018) and studies as well. Previous studies are showing data that is comparable but some deviation is explained due to the place the research has been conducted. Besides the data for the water use only one case project is executed for the analysis of the role of water. Another project may conclude different numbers when floor area of the apartments increase, other materials are applied or façade design changes.

The analysis covers only three materials, aluminium, concrete, and brick, and one case study project. While these materials were selected for their high water intensity or high usage volume, a complete building including many other materials could not be analysed within the available time. The operational water analysis relies on national averages rather than project-specific data, which means that the influence of occupant behaviour on actual consumption is not captured. This could increase or decrease the operational water demand of the project.

Especially the choice for aluminium was based on its high water-demand. However the use of aluminium is in the current day not as common as PVC window frames. It is however projected to be applied more in future projects on the long term (Europian Aluminium, 2019) for the foreseeable future the choice of aluminium may be less relevant for high-rise buildings.

The qualitative component is based on 11 interviews conducted in the Dutch construction, development, regulatory, research and manufacturing sectors. This provides a wide spread knowledge for the research topic but limits more in depth validation on topics like the manufacturing of aluminium or bricks, project execution and change management. A focus group with different parties could have made an extra validation on the results that are provided. The research also focuses exclusively on high-rise residential buildings, which differ from low-rise or mid-rise projects in their spatial constraints, installation complexity, and resident profiles.

5.3 Future research

Several directions for future research emerge from this study. First, the quantitative analysis should be extended to include a broader range of materials to create a more complete inventory of embodied water in residential buildings. Materials like steel isolation and wood would be interesting direction regarding their quantity of usage and steel for its high embodied water use like aluminium. To establish whether a project performs well on water use, a reference level is needed. By analysing what constitutes an acceptable or efficient level of water consumption, project teams can compare their own material-based and operational water use against this benchmark. This allows excessive water use to be identified and reduced, and good performance to be recognised and replicated. Such benchmarking can be applied to both material-related virtual water and operational water consumption

Second, the operational water savings from more advanced greywater or rainwater recycling solutions, such as recycling showers, rainwater tanks and Hydraloop systems, should be measured in real pilot projects rather than relying on manufacturer estimates. Besides the real measurements not all solutions possible were analysed within this research, therefore further exploration to other ways and more in depth research would contribute especially for the societal relevance.

Third, the interaction between water-saving measures and other sustainability goals, particularly CO_2 reduction and material circularity, deserves further investigation to identify potential synergies and trade-offs. This could expose some interesting other barrier and drivers.

Finally, future research should address the multi-scale effects of water use and what they imply for the governance and coordination between ministries, water authorities, municipalities, and developers. While this study shows that building-level choices influence water demand at factory, regional, and national scales, the literature does not yet clarify how these impacts should guide decision-making. Key questions include whether housing should be built in water-scarce regions, whether water-intensive materials like aluminium should be avoided when production relies on stressed water systems, and whether material choices should depend more on where materials are produced than where buildings are located. Investigating these questions would help translate multi-scale water impacts into practical guidance for contractors and policymakers.

5.4 Recommendation

The findings point to a clear starting point: developing contractors should use their central position in the project network to raise awareness and start asking the right questions. The simplest but most powerful step is to ask suppliers for water-use data alongside the CO_2 data they already request. The CO_2 example in this research shows that this single action forced suppliers to rethink their production processes and start a conversation about reduction. The same can happen for water. At the same time, contractors can start themselves by integrate small wins into projects immediately: choosing efficient fixtures, applying SlowFlow drainage tiles, and including a water-impact check in early design reviews. These actions cost little, require no regulatory change, and build organisational experience that makes bigger steps easier later on.

Other stakeholders have their own leverage. Municipalities, as seen in The Hague, can drive change by linking water buffering directly to environmental permits. This turns a barrier into a driver without waiting for national regulation. Suppliers, when asked, can provide transparency on water use in their production processes and compete or could start competing in lower water footprints the same way they now compete on lower CO_2. Clients and investors can include water performance in their project ambitions, creating demand where currently there is none. And residents, while harder to influence directly, can be supported through awareness, smart metering and feedback that makes their daily water use visible and are confronted with their use positive and negative.

What makes the current moment relevant is that water appears to be where CO_2 was a couple of years ago: invisible in procurement, absent from design discussions, and lacking regulatory pressure. But unlike CO_2, water scarcity is local. A shortage in one region does not create urgency in another, which means regulation will likely emerge unevenly. Developing contractors who act now, by building knowledge and testing solutions in their own projects, will be ahead when those regional pressures arrive and water becomes a standard part of project delivery.

6. Conclusion

This research set out to answer the question: what is the role of water in residential high-rise buildings during material production and the operational phase, and how can developing contractors operationalise (circular) water-saving solutions within their projects?

The findings show that the role of water in high-rise residential development is both large and largely invisible. Water use is not limited to the daily consumption of its residents but a substantial share of the total water footprint is already determined before a building is occupied, during the production of materials such as aluminium, concrete, and brick. The analysis of the Lomanlaan case demonstrates that the embodied water in construction materials equals roughly 29 years of operational water use, meaning that almost one-third of the total lifecycle water demand is fixed in the A1-A3 production phase alone. Operational water use accounts for the remaining two-thirds over the building's 75-year lifespan.

The timing analysis reveals that the most influential decisions are made early in the development process. Material selection, design specifications, and procurement strategies determine the water footprint in ways that cannot be corrected later. The production of aluminium, concrete, and brick is concentrated in the A1-A3 phase, and each material shows distinct patterns: aluminium requires continuous high-purity water across its entire production chain, concrete uses most of its water for washing equipment rather than mixing, and brick production embeds its water demand through firing methods and fuel choice.

The impact analysis shows that water use operates across multiple scales simultaneously. At the building level, the choice of materials and fixtures determines direct water demand. At the regional level, potable water scarcity in the Netherlands increasingly constrains where and how many homes can be built. Water utilities already report that supply reliability cannot be guaranteed in several regions, and up to 10 million cubic metres of additional annual production is needed to supply the planned 900,000 new homes. This connection between building-level decisions and regional water availability makes water a strategic rather than merely a technical issue.

Regarding the second part of the research question, the findings show that the implementation of circular water-saving solutions is shaped by five interconnected factors: knowledge and awareness, municipal requirements, financial feasibility, rules and regulations, and execution and maintenance. The first barrier to overcome is low awareness: most practitioners do not realise how large the water footprint of materials is. Municipal requirements, particularly in cities such as The Hague, are becoming a strong driver by linking water buffering directly to environmental permits. However, financial feasibility remains a serious obstacle: systems such as greywater reuse have payback periods of up to 60 years, for only the extra piping, under current water prices. This makes them unattractive within real-estate business cases. Furthermore, Dutch regulations still limit the use of rainwater and treated greywater indoors, while the approaching KRW targets increase pressure to act.

Despite these barriers, the research shows that developing contractors have meaningful room to act. While they cannot change industrial production processes, they can influence material choices, ask suppliers about water use, and select lower-water alternatives where available. For the operational phase, the most feasible solutions are water-efficient appliances (showers and dual flush toilet), which require

no additional piping and offer predictable savings. Greywater reuse systems and recycling showers offer larger reduction potential but face financial and maintenance hurdles. Infiltration solutions such as cascade systems and slow-flow drainage tiles already work well in high-rise buildings and help meet municipal requirements. By applying the concept of small wins, contractors can start with simple measures, build organisational learning, and prepare for more comprehensive circular water strategies in the future.

In conclusion, water plays a significant but still underestimated role in high-rise residential development. Its reduction requires early integration of circular principles, awareness across the project team and supply chain, and organisational commitment. By operationalising circular water strategies, developing contractors can contribute to more resilient housing development, ensuring that the built environment not only consumes water but also respects its limits. What may appear to be just drops on a hot plate can, when many come together, actually cool the plate.

7. References

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In the preparation of this document, CoPilot an Anara, both Large Language Model developed by Microsoft and Anara, was used to support the formulation and structuring of the text. The content has been reviewed by the author and adjusted where necessary.

8. Appendices

Appendix 1 – Drawings Lomanlaan
Appendix 2 – Calculation quantity role of water
Appendix 3 - Consent forms and interview protocol
Appendix 4 – summary and key takeaways interviews
Appendix 5 – Dosis duurzaam water
Appendix 6 – Reflection

Appendix 1 – Drawings Lomanlaan

Appendix 2 – Calculation quantity role of water

Appendix 3 – Interview protocol & consent form

Interview protocol

1. Prior to the interview checklist

Before conducting the interview, several practical and ethical arrangements are made to ensure a smooth and compliant data collection process. This includes reserving a suitable and quiet interview room either online or in person, preparing and testing recording equipment and arranging secure storage for the data. The informed consent form is sent to the interviewee in advance, allowing sufficient time to review the study information and ask questions. These preparations help ensure that the interview can be conducted efficiently, ethically and without unnecessary interruptions.

2. Interview Setup

- Format: Semi-structured interview
- Setting: In person or virtual through Microsoft Teams
- Duration: between 30 – 60 minutes
- Recording & Confidentiality: Participants are recorded, transcribed and the data for interviewees is pseudonymised when recordings are transcribed. Data will be used solely for academic purposes within this TU Delft master's thesis. After transcription, audio files will be deleted.

7. Introduction and consent

At the start of the interview, it is noted that the recording will be started. Only when the consent form is signed. The researcher starts introduces themselves and thanks the interviewee for participating. The purpose of the study is briefly explained, as well as the focus of the interview and its approximate duration. The interviewee is informed about anonymous data handling, confidentiality and their voluntary participation. It is asked again if the interviewee has any other questions before the interview starts and lets the interviewee introduces themselves.

Consent form

Consent form research: Role of water in residential developments

U wordt uitgenodigd om deel te nemen aan een de master thesis onderzoek genaamd: De rol van water voor residentiele projecten. Dit onderzoek wordt uitgevoerd door Anne Meijne van de TU Delft en in samenwerking met Era Contour. Deze master thesis is onderdeel van het afronden van de masters thesis voor de master Management in the Built Environment van de TU Delft.

Het doel van dit onderzoek is om de rol van water te bepalen in residentiele hoogbouw projecten tijdens de materiaal productie en uitvoering van het project en hoe (circulaire) waterbesparing toepassingen geïmplementeerd kunnen worden binnen de organisatie en de projecten. Het interview zal ongeveer 60 minuten in beslag nemen. De data zal gebruikt worden voor de academische publicatie van de master thesis, bedrijf aanbevelingen voor (circulaire) waterbesparing oplossingen en leer doeleinden. U wordt gevraagd om vragen te beantwoorden over:

- De mogelijkheden voor (circulaire) watergebruik reductie oplossingen in de constructie en gebruiksfase voor hoogbouw projecten.
- Barrières en mogelijkheden voor de toepassing van (circulaire) watergebruik reductie oplossingen voor tijdens de constructie en de gebruiksfase van hoogbouw projecten.

Zoals bij elke online activiteit is het risico van een databreuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico's door de data te pseudonimiseren en alleen dat wat nodig is voor de beantwoording voor het onderzoek.

Open data is niet van toepassing op dit onderzoek en de data van het interview wordt verwijderd na het afronden van dit onderzoek.

Uw deelname aan dit onderzoek is volledig vrijwillig, en u kunt zich elk moment terugtrekken zonder reden op te geven. U bent vrij om vragen niet te beantwoorden. Als u later uw reactie op sommige vragen of het gehele interview wilt intrekken heeft u 7 dagen bedenktijd om dit naderhand te doen.

Voor verdere informatie of vragen, neem contact op met onderzoeker Anne Meijne.

Door middel van het ondertekenen voor dit pseudonomised interviews, ga je ermee akkoord om deel te nemen in dit onderzoek.

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. Ik heb de informatie over het onderzoek gedateerd 26-01-2026 gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	☐	☐
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	☐	☐
3. Ik begrijp dat mijn deelname aan het onderzoek de volgende punten betekent: een audio-opname van het interview, waarvan een transcriptie in gepseudonimiseerde vorm zal worden gemaakt. Deze opname zal daarna worden verwijderd om de het uitlekken van persoonsgegevens te minimaliseren.	☐	☐
4. Ik begrijp dat de studie na het publiceren en het afronden van de studie eindigt.	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt namelijk het minimale risico dat in de interviews over de organisatie processen, feiten en kennis wordt gesproken maar dat sommige hierdoor stress ervaren door hun werk en dit mogelijk naar boven komt tijdens het interview. Ik begrijp dat deze risico's worden geminimaliseerd door de vragen die worden gesteld en de mogelijkheid om een vraag over te slaan of uit het interview te stappen.	☐	☐
6. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld, met het risico dat ik hieruit geïdentificeerd kan worden door de link die te maken is met het project of het expertise vakgebied waarin gewerkt wordt.	☐	☐
7. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een databreuk te minimaliseren, en dat mijn identiteit op de volgende manieren wordt beschermd in het geval van een databreuk door middel van alleen de data de verzamelen die voor het onderzoek relevant is en als uitspraken vanuit het interview worden gebruikt in het verslag wordt dit expliciet gevraagd. De data wordt gepsuedonymiseerd en op de TU Delft OneDrive opgeslagen.	☐	☐
8. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals naam en contactgegevens, niet gedeeld worden buiten het studieteam.	☐	☐
9. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt na het afronden van de studie.	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
10. Ik begrijp dat na het onderzoek de geanonimiseerde informatie gebruikt zal worden voor het beantwoorden van de onderzoeksvragen van dit onderzoek en het publiceren hiervan.	☐	☐
11. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdrages anoniem te quoten in resulterende producten.	☐	☐
12. Ik geef toestemming om mijn naam te gebruiken voor quotes in resulterende producten	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
13. Ik geef toestemming om de gepseudonimiseerde data (audio transcript, data en consent form) die over mij verzameld worden gearchiveerd worden in de TU Delft OneDrive van de onderzoeker opdat deze gebruikt kunnen voor tijdens het onderzoek en de quotes en worden voor toekomstig onderzoek en onderwijs.	☐	☐

Signatures

_____	_____	_____
Naam deelnemer	Handtekening	Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

_____	_____	28-04-2026
Anne Meijne	Handtekening	Datum

8. Interview questions

Because most interviewee contributed expertise from a different part of the construction and material supply chain, the interview questions were tailored to their specific role. For this reason, the corresponding question set is included before each transcript in appendix 5.

9. Closing

At the end of the interview, the researcher thanks the interviewee for their time and valuable contributions. It is checked by the researchers that all relevant topics have been discussed and that the interviewee has no additional comments or questions. The recording is then stopped and securely saved.

Finally, the interviewee is reminded of their right to withdraw or amend their responses within the agreed timeframe and the next steps of the research process are briefly explained.

Appendix 4 - Summary and key takeaways interviews

Interview	New information	Key takeaway
Interview 1: Consultant sustainable concrete & coordinator sustainable solutions	The new insights from the interview are on the hidden water impacts of concrete production and the types of water used. While a cubic meter of concrete contains roughly 160 to180 liters of water, only about 100 to120 liters are intentionally added to the concrete mixture. The rest is moisture already present in sand and aggregates (toeslag materialen). However, the consultant explains that the real water use is much higher, especially when materials such as sea sand or sea gravel are used (not normally the case in The Netherlands at least). These materials must be washed extensively with freshwater to remove salt, as this salt is bad for the concrete. This type of water use is often invisible in EPDs. The consultant also highlights that recycled aggregates through urban mining can drastically reduce water use because their processing is intentionally a dry process and that wetting the material would reduce the quality of recyclable cement. Additionally, the consultant stresses that primary sand and gravel extraction in the Netherlands has major ecological impacts, creating deep artificial lakes with a disturbed or no life present within the lake. A dimension not captured or warned in LCA water indicators. Finally, when looking at possibilities to reduce the water, the use of third-generation superplasticizers can reduce water demand by up to 30 liters per cubic meter of concrete.	Key takeaways include the importance of distinguishing between the visible water use (mixing water, wash water for the mixers) and the more hidden water use and impact for the making of concrete (washing of aggregates, extraction impacts). The consultant emphasizes that the water added at the concrete plant for the concrete mixture is only a small fraction of total water use. This is only just one quarter of the full A1–A5 (production phase) water footprint. Urban mining concrete is identified as the most water-efficient option due to its dry process of recycling the concrete that they won from the already existing built environment. On top of this water reduction it also reduces the need for primary extraction and the effects this has on the environment. Prefab factories increasingly use rainwater buffers to replace freshwater, with additional industrial water when there are long dry periods. Wash water from concrete trucks is collected, settled, and reused for a small part, but cannot be used in all mixes due to quality constraints. However for the making of concrete fresh water is mainly used. The consultant also notes that water is not yet a major topic in the construction sector, unlike CO_2 and circularity, meaning the research is good and relevant at this moment. Finally, the interview confirmd that meaningful water reduction requires a combination of material choice,

	This does not only lower water use but also the cement need and therefore CO_2 emissions.	process innovation, and better visibility of water flows in LCA data.
Interview 2: LCA expert	The interview provides several new insights into how water is calculated and shown within LCA calculation. The EcoInvent tool is very insightful but needs a good understanding how to read it. With water there is a misleading perception that water has little relevance in environmental assessments this is due to the in out outflow of the water within the processes. The water that is calculated is the actual water multiplied with a factor which represents the scarcity or the abundance in the region. The expert also explains that real-world water scarcity is growing, even though LCA results do not fully reflect this trend and the quantity in the scores. Furthermore, the commonly used Water Depletion Potential (WDP) indicator is currently unreliable due to modelling issues in EcoInvent, especially around inflow/outflow balances and allocation. As a result, freshwater use (FW) is a more trustworthy metric. Finally, the interview highlights that the location of water use matters greatly, since the same volume of water can have very different impacts depending on regional scarcity or abundance.	Four key takeaways for the research are: First, rely on FW (freshwater use), if it is possible to get the numbers of FW, rather than WDP, as WDP is unstable and may lead to incorrect conclusions. Second, use NMD and EPD data as your primary sources, since SimaPro is too complex to master within the timeframe of the research and is not intended for whole-building analysis (too much factors and input, information overload). Third, analyze water use location specific because regional scarcity and process stages and transport from different suppliers strongly influence the water impact. Fourth, be aware that LCAs historically underestimate water issues and calculates them in a strange way so environmental relevance must be interpreted beyond the numeric scores of the LCA.
Interview 3: Specialist sustainability and legislation & coordinator sustainable solutions	The interview with the specialist sustainability and legislation together with the coordinator sustainable solutions who was also interested, provides new insights into how water appears in LCA calculations and how upcoming regulations may affect construction	The key takeaway is that water will become a more important constraint in construction. Not because of technology, but because of regulation and scarcity. LCA water indicators are still unreliable, so developers should focus on clear, practical insights such as avoiding

	projects. He explains that ERA mainly focuses on MKI and CO_2, and that water is not yet a major topic in the sector. Water indicators in LCA (FW and WDP) are difficult to interpret: FW shows actual freshwater use, while WDP includes scarcity factors and can behave strangely due to inflow/outflow modelling. They confirm that water use in concrete production is often underestimated, especially when sea sand must be washed with freshwater. He also highlights that the EU Water Framework Directive (KRW) will become increasingly important. After 2027, developers may face stricter requirements for dewatering, including testing for 42 chemical substances and possibly ecological indicators. This can increase costs and delay permits. He notes that drinkwater scarcity will become a real issue, and tenders already ask for rainwater buffering or reuse. However, decentralized water reuse systems often lack a good business case because potable water is cheap.	sea-sand concrete and understanding regional water impacts. KRW regulations will make dewatering more complex and costly, meaning early coordination together with water boards is essential. Water-saving systems in buildings are technically possible but financially weak unless it becomes required by tenders, permits or sustainability goals like with CO2. For ERA Contour, the most realistic short-term actions are: preparing for stricter dewatering rules, and integrating simple water-saving measures where they support tenders or client ambitions.
Interview 4: Director urban concrete recycling & coordinator sustainable solutions	The interview with the urban concrete recycling company showed how recycled concrete can drastically reduce water use in material production of recycled concrete. The company uses a dry separation process to turn demolition concrete into new aggregates, avoiding the large amounts of freshwater normally needed to wash sand and gravel. This contrasts with other recyclers who still use water-based cleaning. He explains that dry processing not only saves water but also perceives	The company demonstrates that urban mining is one of the most water-efficient options for concrete production. Dry processing avoids the hidden water use found in traditional aggregate washing and harvesting. It also reduces environmental damage from primary extraction and supports circular construction goals. For developers, choosing recycled aggregates is a practical way to reduce water use and CO2 in the A1–A3 phases without major design changes. The main barrier is

	the possibility to reuse the recovered cement fraction. They also highlight that using recycled aggregates reduces the need for primary sand and gravel extraction, which has major ecological impacts in the Netherlands. The interview confirms that recycled concrete can meet structural requirements and is increasingly used in new projects.	availability, money and logistics, not technology.
Interview 5: Area developer	The interview with the area developer provides insights into the technical and practical challenges of implementing (circular) water systems in buildings. He explains that systems like rainwater reuse, greywater recycling and underground storage are technically possible but often expensive, space-intensive and difficult to maintain. Many solutions require extra piping, separate water loops and dedicated technical rooms. He also notes that Dutch regulations still limit the use of treated greywater for household applications, making many systems legally complex. He highlights that residents and housing associations are often hesitant because systems require maintenance and can cause hygiene concerns. As a result, most circular systems remain pilots rather than standard practice.	Circular water systems face barriers in cost, maintenance, regulation and user acceptance. Developers prefer simple, low-risk solutions and will most of the time not start applying other solutions unless municipalities require more ambitious measures. The area developer is starting to apply some (water)saving solutions but these are possible because of funding for the specific water saving solutions. For now, the most realistic options are rainwater buffering and irrigation reuse, while greywater systems need clearer regulations and better long-term management structures before they can scale up.
Interview 6: Adviser/ researcher water	The interview explains that the adviser/researcher water developed a new calculation tool for operational potable water use within the GPR Gebouw software. This tool was created because wanted to create a tool which works with national measurements and regulations. Plus to get real insights	The key takeaway is that the new GPR drinkwater tool finally makes operational water use measurable in a user friendly tool. This allows developers to design for lower water consumption to score points in tenders. It gives early insight into how design choices such as low-flow fixtures, rainwater reuse, or

	on the implications on water-saving solutions. The tool is based on the EU Levels methodology, which the company he works for adapted and simplified for the Dutch context. It calculates water use for all installations in a dwelling (toilets, taps, showers, appliances) and includes factors such as pipe lengths, hot-water waiting losses, system efficiencies, and reuse options (rainwater, greywater, recirculating showers) but simplified them for a user friendly tool. It also integrates Dutch CBS data for default user behaviour and uses Dutch hydrological data for rainwater availability. The tool allows developers to test design variants early in the process and see how choices affect water consumption.	recirculating showers affect total water use. The tool is user-friendly, can be applied from early sketch design to final design, and aligns with European sustainability standards. It also fills a gap left by MPG/LCA tools, which do not calculate operational water use. By using the tool, developers can make more informed decisions and integrate water reduction into project design in a measurable and structured way.
Interview 7: Sales director smart metering tool	The interview with the Sales director smart metering tool shows how digital water monitoring can reduce water use and prevent losses and resulting costs in buildings. He explains that water in the Netherlands is extremely cheap, which means most users feel no financial pressure to save water. Large companies, pension funds and hotel chains are now becoming more active because new EU rules (CSRD) require them to report water use and reduce risks. The smart metering system is placed on existing analogue water meters with a small camera device, making installation simple and fast. They read the meter and can detect leaks very accurately and report that around 30% of buildings have some form of leakage, often unnoticed toilet leaks or dripping taps. The water suppliers in	Smart metering tools shows that monitoring and leak detection is one of the easiest and most effective ways to reduce water use in buildings. The technology is simple, scalable and works on existing meters. The biggest barriers are the legislation next to the low water prices and lack of awareness, not technical limitations. For investors or building owners, the main benefits lies in preventing costly leaks, meeting new reporting obligations (CSRD, GACS), and improving sustainability scores (BREEAM, GRESB). Water savings alone rarely justify the investment, but the combination of risk reduction, compliance and operational insight makes monitoring a strong strategic measure. For housing projects, the smart metering is especially relevant for VVE’s and large portfolios, where

	the Netherlands also have around 30% of leakage within their potable water pipes. These small leaks can waste thousands of liters per day and cause massive consequences if a room or apartment can't be used. Their service can reduce water use by around 20%, mainly through awareness and early leak detection. The main value for clients is not the water savings alone, but preventing damage, meeting sustainability reporting requirements which can result in higher subsidies or certificates for which more money can be asked, and improving building performance.	leak detection and submetering can significantly improve performance and reduce waste.
Interview 8: Professor fusion of interest for housing transformation	The interview with the professor for fusion of interest for housing transformation provides new insights into the behavioral and social side of successfully implementing (circular) water-saving solutions for residents. She emphasizes that technical solutions alone rarely achieve their intended impact if residents do not understand, trust or consistently use them. Many sustainable systems fail because they are experienced as complex, inconvenient, or poorly explained what it's good for and how they can benefit. She highlights that residents respond strongly for their own comfort, clarity and ease of use; if a system requires extra effort or maintenance, adoption drops quickly. She also notes that implementation timing matters. Residents are most open for change at key life moments and when they financially benefit (moving in, renovation, or when costs rise). Furthermore, she highlights that the	The key takeaways underline that behavioral factors are critical for the success of the usage of (circular) water-saving solutions. Systems must be easy to use, invisible in daily use, and require minimal action from the resident to achieve meaningful savings. Developers should avoid placing responsibility for water reduction solely on occupants and instead design solutions that work automatically or collectively. Clear communication, explanation, user-friendly use and maintenance-friendly significantly increase acceptance. Her insights show that the social side of sustainability consisting of trust, comfort, and perceived effort is just as important as the technical side. For (circular) water-saving strategies to succeed in housing, they must be embedded in resident experience, not added on top of it.

	implementation of collective systems often perform better than individual ones because they remove behavioral responsibility from residents and centralize maintenance and monitoring.	
Interview 9: Senior Policy Advisor Public Law & Coordinator SVHC	The interview provides new insights into how national water policy, the EU Water Framework Directive (KRW), and local governance influence housing development. Although “water and soil guiding” is politically emphasized and warned for, he explains that in practice little changes happen. Municipalities, provinces and water boards continue their negotiation game, and differences between regions or municipalities are expected to grow. Water boards increasingly assert stricter positions, especially regarding groundwater, infiltration and building in vulnerable areas. The interview also clarifies that the KRW already applies since 2000, but enforcement has been largely avoided because compliance would block many activities. After 2027, stricter enforcement and heavier proof requirements are expected, especially for dewatering (bemaling). For the future developers may need to test in the future for the 42 assigned priority substances and potentially 122 ecological indicators, which can significantly increase project costs. Temporary disturbing or worsening the water quality may become allowed under new EU revisions, but only with strict justification for what you do it for. He also notes that decentralized rainwater or greywater systems in new buildings have limited national	The key takeaways show that regulatory pressure around water quality and dewatering can become a major bottleneck for housing projects, not because of new rules but because existing KRW obligations will be enforced. Developers must anticipate higher investigation costs, stricter proof of not disturbing or worsening the water quality and levels, and region-specific requirements from water boards. Early engagement with local authorities and understanding regional water priorities becomes essential for project feasibility. Decentralized rainwater or greywater systems may reduce potable water use at building level, but they do not meaningfully reduce national demand and can conflict with groundwater infiltration objectives. For developers, the most effective strategy is not technological first, but regulatory literacy: knowing local water board positions, understanding KRW implications, and preparing mitigation or compensation measures early. Overall, the interview highlights that water constraints in area development will intensify, and that governance and compliance, not technology, will shape what is possible.

	impact, since 99% of the housing stock already exists. He warns that such systems can conflict with groundwater infiltration goals and often lack a feasible business case.	
Interview 10: Regional sales manager greywater recycling	The interview provides detailed insights into the technical functioning, spatial requirements and market conditions for applying Hydraloop greywater systems in high-rise residential buildings. The manager explains that Hydraloop offers two systems: the H300 for single-family homes and the larger H600 for apartment buildings and commercial facilities. The H600 units can be installed in cascades, allowing them to process greywater from multiple apartments efficiently. For a building with around 200 residents, 9–13 H600 units are needed depending on whether the system supplies only toilet flushing or also washing machines. Each unit requires limited space (0.8 × 0.8 × 2 m) and only standard piping, plus a separate greywater stack. Installation adds roughly €500 per apartment, and maintenance costs are about €100 per unit per year. The interview also reveals that Hydraloop holds a unique RIVM exemption allowing greywater reuse in multi-unit buildings, bypassing outdated Dutch regulations that still prohibit shared greywater systems. Adoption in the Netherlands remains slow due to low water prices and lack of regulatory incentives, while uptake abroad is driven by scarcity, high water tariffs or strict local requirements. Early adopters in the Netherlands implement Hydraloop	The key takeaways show that greywater recycling is technically feasible, spatially manageable and safe for high-rise housing, but implementation in the Netherlands is hindered by structural barriers. The main obstacles are economic—water is too cheap to justify investment—and regulatory, as outdated laws still restrict greywater reuse despite Hydraloop's certified safety standards. Developers also face practical challenges such as additional piping, technical room space and long-term maintenance responsibilities, which make them cautious unless sustainability ambitions or municipal requirements push adoption. International examples demonstrate that when water scarcity or pricing creates urgency, greywater systems become standard practice, suggesting that policy incentives or regulatory changes will be essential for large-scale uptake in the Dutch housing sector. Overall, the interview confirms that the technology is ready, but the Dutch market and regulatory environment are not yet aligned to support widespread implementation.

	mainly from sustainability ambitions rather than financial returns.	
Interview 11: Site manager Linck in the Binck	The interview with the site manager of Linck in the Binck provided detailed insights into the practical and technical reality and constraints of implementing circular water systems in high-rise residential buildings. Although solutions such as greywater reuse, rainwater buffering and cascading irrigation systems are technically feasible, they introduce significant spatial, financial and operational challenges. Greywater systems require additional vertical piping which complicate the already full shaft and underneath space of the building. The building of Linck is comparable with Lomanlaan with a central core where the lift and staircase is placed. More advanced options such as water bags beneath the building for greywater reuse of toilets or washing machines or fully integrated greywater loops like Hydraloop, are described as costly, space-intensive. With no space available and digging a water basin a very expansive alternative and difficult and important to maintain. The contractor notes that maintenance-heavy technologies, such as recycling showers, face resistance from housing associations and residents due to reliability concerns.	The key takeaways highlight that while circular water systems are technically possible (if implemented early on and with extra room reservation), their adoption in high-rise housing is constrained by a combination of regulatory, financial and operational barriers. Developers and contractors tend to avoid complex systems because they require additional space, introduce long-term maintenance responsibilities, and increase project risks. Housing associations and investors also avoid maintenance concerns. As a result, the sector always prefers if it is not mandatory or generates money toward simpler, low-risk measures. Solutions such as rainwater buffering or water reuse will only be applied unless strong municipal requirements or sustainability ambitions justify more advanced systems. Overall, the implementation of (circular) water-saving solutions will require clearer regulations, better coordination between stakeholders and financial or policy incentives that make these solutions more attractive for residential development.

Appendix 5 – Dosis duurzaam water

Appendix 6 – Reflection

Throughout this graduation project, my research direction developed through a combination of initial curiosity, supervisory guidance, and practical engagement with ERA Contour. I began with a broad interest in circularity with my chosen topic, a theme that offered many possible research paths. Early discussions with ERA Contour, introduced water as a potential topic alongside materials or nature. Although materials aligned with my previous HBO research, the topic of water immediately sparked my interest because it felt new, relevant, and underexplored. Through literature study and conversations with my supervisor, who one of them had previously researched water, confirmed that this was a promising direction.

As the research progressed, I discovered that the role of water in material production where I was looking for was more limited than expected. The literature was sometimes scarce, and interviews confirmed that water use in construction materials is often overlooked or treated as a cost-driven process. This required me to adapt my approach. While calculating water use across different phases, I realised that the operational phase held far greater potential for meaningful insights than the construction phase. This was found to have little contribution on the water demand. Especially given the growing societal attention to potable water scarcity the construction phase was changed to the operational phase. This shift in focus became a turning point, allowing the research to evolve into a more relevant and impactful direction.

Towards the end of the process, the research gained clearer focus, particularly regarding the final sub-question. Initially, the intention was to examine both project-level and company-level implementation, but these perspectives proved too be too broad and too different in scope for one thesis. Through discussions with my supervisors and insights from the interviews, the focus was refined to project-level implementation, which had already emerged as the most relevant and feasible angle for this research.

Methodologically, the thesis required me to connect different domains; technical, organisational, and environmental. Using EPDs, literature, and interview data in combination created a grounded calculation method that allowed for cross-checking and nuance. At times, conflicting results forced me to stay critical and refine my assumptions. The methodology also provided structure when the research risked drifting, helping me maintain focus while still exploring new insights.

The process was not without challenges. The relatively new topic meant that practitioners often had limited knowledge, especially regarding on how to calculate it. Tools such as WDP factors and AWARE indicators proved insufficient for capturing the full picture of water flows, which limited their applicability. On a personal level, the large amount of work required to produce a strong thesis sometimes felt overwhelming. Balancing academic accuracy and sometimes high over connection with societal relevance, especially while working within a company, was challenging. Yet these challenges taught me to prioritise, stay critical, and accept that not every question can be answered for everyone within one thesis.

Looking back, the academic value of this research lies in contributing to an emerging field by offering structured insights into water use in high-rise residential development. The interdisciplinary nature of the topic aligns well with the MBE track, which teaches you how to manage complex processes across the buildings lifecycle. Something that could be compared to writing a thesis. Working on a subject

that is not traditionally associated with MBE also strengthened my ability to navigate outside the box of topics which is also the case in practise. In that sense, the functioning of the research reflects the essence of the AUBS programme: dealing with multifaceted challenges in the built environment and translating them into actionable insights for practice not through a design but through insights and recommendations. The societal value became increasingly clear as reports on water scarcity continued to appear during my research. By clarifying the role and responsibilities of developing contractors, the thesis supports earlier integration of water considerations in project development, contributing to long-term water security and circular ambitions.

This project would not have been possible without the guidance of my supervisors. Karel van den Berghe challenged me to think more critically and helped me refine the “what” behind the research questions. His enthusiasm for exploring water within construction was motivating throughout the process. Vincent Gruis provided structure, clarity, and direction, often identifying what I needed before I articulated it myself. His ability to ask targeted questions helped me navigate moments of uncertainty. I am also grateful to ERA Contour for their practical insights, willingness to brainstorm, and genuine interest in applying the findings in practice. Their involvement grounded the research and made it more meaningful.

Reflecting on the graduation period, I look back on a process that was both demanding but in the end really rewarding. Moments of being lost and wondering where is this going to? Or what am I contributing with my research? Focus was found and through it all I learned a lot. I enjoyed the investigative aspects the most during the interviews. The conversations with practitioners and the opportunity to visit places I would not normally get to see. The research evolved gradually, sometimes feeling like a step backwards, but ultimately coming together into a coherent whole. The interplay between focus and overview was a constant challenge, but also a valuable learning experience that strengthened my skills as a researcher.

Overall, this thesis has contributed to my academic development, expanded my understanding of circular water use, and reinforced my ability to manage complex research processes. Skills that I will carry forward into my professional career.