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# Historical development of four Dutch urban drinking water infrastructures

KWR Watercycle Research Institute

# BTO

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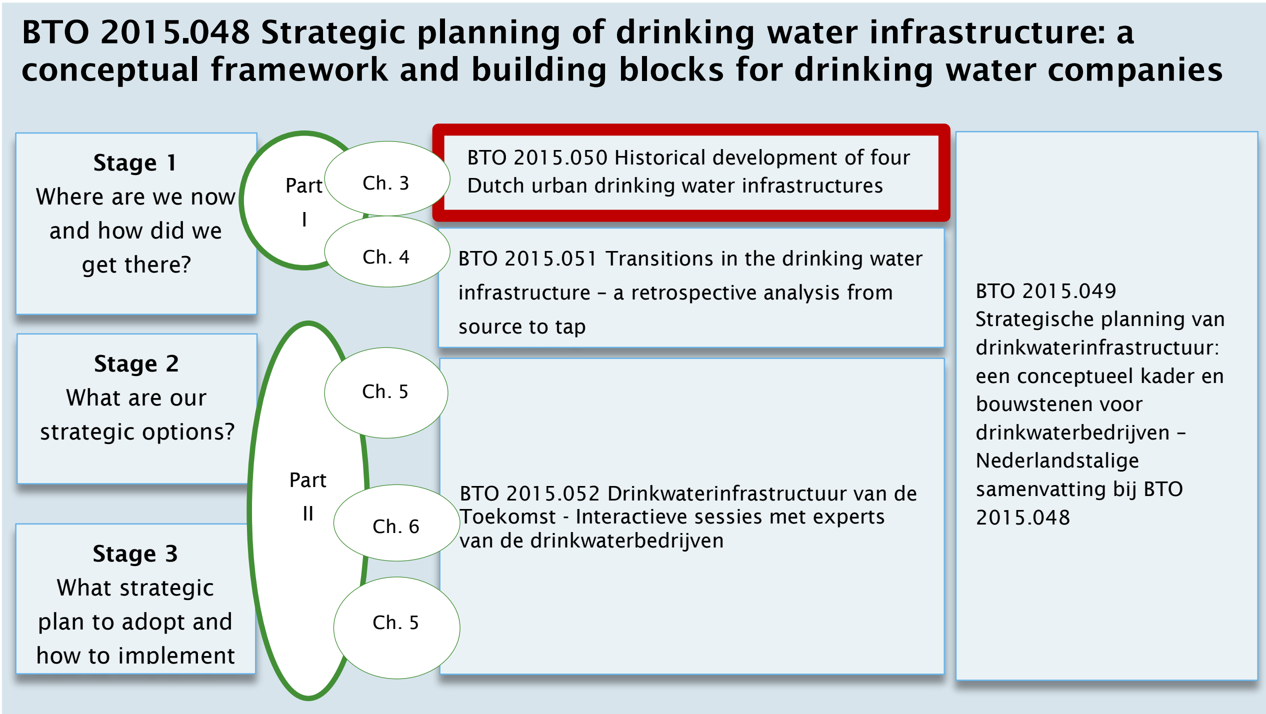
# Foreword

Within the Joint Research Programme of the Dutch drinking water companies (BTO) explorative research was conducted on how to best take possible futures into account when making strategic plans on drinking water infrastructure. Several reports were produced: the overall report, a Dutch extended summary, and in depth background info on chapters 3, 4 and 5 of the report (see schema below). This report is the report on Historical development of four Dutch urban drinking water infrastructures, and provides detailed background info to chapter 3 of the main report.



# Summary

This report describes the results of a study of the infrastructural developments of four different Dutch urban drinking water systems and the identification of the drivers behind these changes. The major investments in the drinking water infrastructure of the four Dutch urban areas of Amsterdam, Groningen, Arnhem-Nijmegen and Maastricht were identified as well as the drivers behind the investments. This study is part of the project 'drinking water infrastructure of the future', in which critical insights and lessons learned from past transitions will be used in exploring plausible future transitions. This report provides detailed background info to chapter 3 of the main report: BTO 2015.048 Strategic planning of drinking water infrastructure: a conceptual framework and building blocks for drinking water companies.

The research objectives were to identify the changes that occurred, the main drivers and the main actors behind these changes. More specifically, the research questions objectives of this study were:

- What are the most important developments in the drinking water infrastructure of the Dutch cities in the past decades?
- What are the most important drivers, reasons or incentives for these developments and investments? How can these drivers be classified? Can the drivers be classified as internal (within the company itself), external (e.g. policy, climate, behavior, etc.), or transitional (company may have some influence but also depends on external actors).
- Which patterns, trends and drivers with respect to investments in the drinking water infrastructure can be distilled from these analyses?

*Theoretical concepts*
Drinking water infrastructure is considered in an integrated and holistic way. That is, firstly, taking into account the various subsystems of drinking water infrastructure from 'source to tap' (i.e. water extraction, treatment, distribution systems and appliances in the household). Secondly, drinking water infrastructure should be considered a sociotechnical system, whereby its many physical components (such as treatment technologies or distribution systems) are inextricably linked to social and organisational processes (such as its design and management).

Another premise relates to the way transitions are defined. Transition is a change from one sociotechnical configuration to another, involving substitution of technology, as well as changes in other elements (Geels 2002). Such other elements include user practices, regulation and symbolic meaning. Geels (2002) developed the Multi-Level Perspective (MLP) to distinguish between niche-innovations, the sociotechnical regime and sociotechnical landscape. Using these three levels, the different (f)actors that influence a transition can be traced and described, as well as their interrelations.

A last important conceptual premise relates to the so called spheres of influence, whereby a distinction is made between an internal and external environment and a transactional space. The internal system comprise of all those infrastructural aspects drinking water companies have full control over, whereas the external system include trends and developments water companies have no control over, but which do influence the drinking water system. The

transactional space is the grey area between the in- and external environments. Water companies have no full control over developments in this space, but can exert influence, for instance by drawing up strategic agendas with important third parties.

*Methodology*

To describe the development of the drinking water infrastructure in the Netherlands, four cities with different characteristics were selected: Amsterdam, Groningen, Arnhem-Nijmegen and Maastricht. The major investments of the primary drinking water infrastructure (abstraction, treatment, storage and distribution) were identified for the period of 1850 – 2014, based on literature research and interviews with drinking water professionals. All identified reasons and incentives for 225 identified investments were classified to a limited number of 23 drivers. The occurrence of the drivers was analysed for each city and for three time periods (< 1960; 1960 – 1985; 1985 – 2014). Changes in the spheres of influence were studied by analysing the occurrence of internal, transactional and external forces behind the drinking water infrastructure investments.

*Infrastructural development Groningen*

The first surface water facility of Groningen was built in 1880 and is still in use. This facility has been adapted several times between 1880 and 2012. The source changed from surface water only, to mixed treatment of surface- and groundwater, to groundwater only, and since the early 1970s both surface water and groundwater are used and treated in a separate configuration. The treatment of the surface water was gradually expanded, in order to adapt to variations of the source water quality and meet more stringent water quality standards, because of technological development and in order to meet the growing water demand. In the beginning of the 20th century, the city had two water companies (a private enterprise and the municipality); some districts had two distribution networks. At the end of the 20th century the city of Groningen had grown, but the water production of the municipality stagnated because the municipality got 'isolated' by the provincial water company for which the municipality could not grow further, and the water consumption in the city had stagnated. Shortly after, the municipality and the provincial water company merged. (in 1998) The transport capacity of the source water and the drinking water was expanded a couple of times due to the increasing drinking water demand and requirements on security of supply.

*Infrastructural development Arnhem – Nijmegen*

Both the cities of Arnhem and Nijmegen were served by a municipality for a long time. Groundwater is abundant is this region and both cities had one or two treatment facilities for most of the time. Due to the geological situation, both cities have storage reservoirs in the higher parts of the city. The drinking water treatment was relatively uncomplicated, comprising aeration, filtration and conditioning, except for the facility in the city center of Nijmegen which was facing groundwater pollution at the end of the 20th century. The municipalities were acquired by a private enterprise at the end of the 20th century. The municipalities got 'isolated' by the provincial water company. After the merger of the city water companies and the provincial water company, the water supply plans were considered in an integral way on a larger scale. The increase of the scale of production, the desired reduction of groundwater extraction in natural reserves and the hardness of the water of facilities led to the shutting down of certain smaller scale facilities, clustering towards larger scale facilities and larger scale transport of drinking water towards the city and from the city towards rural areas.

*Infrastructural development Maastricht*

The basic outline of the drinking water infrastructure is rather constant during the entire period. Groundwater has always been used as drinking water source. The required treatment of the groundwater has always been limited, although disinfection was required in some cases and the treatment is expanded with softening. The building of a nitrate removal plant could be prevented by cooperating with farmers, as well as mixing with water with low nitrate levels. The city got served by two or three groundwater facilities until the 21st century. Some facilities were closed, because of water quality or capacity problems, only after they could be replaced by new facilities. In the beginning of the 21st century, the switch from separate drinking water production facilities to centralized softening was realized. This project, together with the acquisition of the municipality of Maastricht by the provincial water company WML (around 2000), had great impact on the main distribution infrastructure since water supply plans were considered in an integral way on a larger scale. The availability of groundwater has always been really scarce on the west side of the river, and groundwater was abundant east of the city. Many efforts were done to find adequate groundwater sources on the west side of the river, which was hardly successful because of water capacity and quality problems. This also explains the existence of several transport pipeline connections crossing the river, and the presence of high storage reservoirs at the west side of the city.

*Infrastructural development Amsterdam*

The city of Amsterdam is supplied with drinking water which is produced at two different sites, namely Leiduin and Weesperkarspel. Both surface water facilities were built in the nineteenth century. The Leiduin site was built in 1853 and was initially operated by a private enterprise, the Dune Water Company. In 1896, the concession of the Dune Water Company was sold to the municipality of Amsterdam. For about a century, the Leiduin facility extracted water from the dunes when it was shown that the dunes got depleted and upconing of brackish water occurred. In order to replenish the dunes with freshwater, a large scale pretreatment of river water and extended distance transport works were realized mid-20th century. The Weesperkarspel site was built in 1888, but for many decades the water was not suitable for drinking purposes, because of the poor quality of the source. After several source switches, the river water source was replaced by lake water in the 1930s. Its water quality improved significantly, and therefore the double distribution network, which had separated the potable water of Leiduin and the non-potable water of Weesperkarspel for many decades, could be eliminated. In the past decades, both the treatment of Leiduin and Weesperkarspel have had many capacity expansions and process adaptations, in order to meet growing water demands and anticipate on changes of the source water quality and meeting more stringent quality demands. Also the transport pipeline infrastructure, both of source water and drinking water, and the storage capacity works were expanded many times to meet growing water demands and to increase security of supply. Since 2006, the municipal water company of Amsterdam is named Waternet, and is the first and only water cycle company of the Netherlands.

*Results and conclusions*

The incentives for the 225 identified investments could be classified into 23 different drivers. The drivers ‘water quality’ and ‘water demand’ are the most frequent occurring drivers. Investments because of third parties, geographical factors, costs, and policy are of secondary interest. Some drivers, such as ‘image’ and ‘sustainability’, were only identified one or two times. Most of the drivers found are recurring throughout the entire period, although some trends were found in the occurrence of drivers. Important trends are the search for proper drinking water sources and the increasing customer connectivity and water demand in the early decades. Investments induced by the merger of municipalities and larger scale companies, and the importance of environmental impact and costs occur in the later decades. Despite the presence of common generic drivers for all four cities, its effects on the development of the infrastructure of these cities are influenced by local factors.

The large inertia of drinking water systems – or path dependency – is confirmed, caused by large investments and long life times. However, it is also shown that the system is flexible, meaning that the system can be adapted to cope with changing conditions over the decades. During the time span of a century, several important changes are observed, such as managerial issues regarding company ownership and mergers, continuous capacity expanding to meet the growing water demand and frequent adjusting to changing water quality demands. Larger scale infrastructural sites (with sunk costs) are likely to stimulate continuous development (expanding, modification and renovation) rather than developing new sites. Trends were based on the data of three periods of at least 25 years, and it is suggested to at least analyse a period of halve a century to identify trends or differences in the occurrence of drivers as well as to identify transitions in integral infrastructural drinking water systems.

The analysis of the sphere of influence of drinking water companies shows that the majority of the investments is driven by external factors in the early decades, mostly because the growing water demand drove the increase of the connectivity and the capacity expanding. In the later decades, many of the investments are internally driven, mainly because water companies can decide whether or not facilities need renovation or further improvement. In most cases (periods and cities), the relative occurrence of transactional drivers is smaller than the occurrence of external and internal drivers, although the occurrence of transactional processes seem to increase over time. It is important for water companies to identify and explore their transactional sphere of influence, since it contains possibilities to influence or steer transitions.

# Overview

# 1 Introduction

## 1.1 Project: the future drinking water infrastructure

The target of the project 'Drinking water Infrastructure of the Future' is to explore the future and its implications on the drinking water infrastructure. Also the transitions of these infrastructural states, in the urban area context, are explored, in an integral and multidisciplinary way.

To understand the transitions on urban water infrastructure we have divided the research into two parts. The aim of the first part of the project is to reveal the most important socio-technical drivers and patterns behind historical transitions in the drinking water infrastructure of Dutch urban areas. The second part of the project focusses on the present and the (near) future, and investigates possible future transitions in the drinking water infrastructure. The socio-technical drivers revealed in the historical analyses of the project may support the identification of future transitions in the drinking water infrastructure. Understanding the past transitions provides insight on how future transitions can be managed to guarantee a reliable water service. This report describes the results of the historical analysis of the development of drinking water infrastructure systems in four Dutch cities.

## 1.2 Historical development of drinking water infrastructure of four cities in The Netherlands

To describe the development of the drinking water infrastructure in the Netherlands, four cities with different characteristics were selected: Amsterdam, Groningen, Arnhem-Nijmegen and Maastricht. These cities are situated in different areas of The Netherlands: Amsterdam is in the west, Groningen in the north, Arnhem-Nijmegen in the east and Maastricht in the south. The difference of the location is expressed by geographical factors: Amsterdam and Groningen are developed at flat grounds, whereas Maastricht, Arnhem and Nijmegen also have somewhat accidented surroundings. Amsterdam has many canals and the city is surrounded by water. The cities of Maastricht, Nijmegen and Arnhem are built next to larger rivers. Surface water is used as a drinking water source at Amsterdam and Groningen, and Maastricht, Arnhem, Nijmegen and Groningen use groundwater as a drinking water source.

Within the historical analyses part of the overall project, the research described in this report focusses on the following questions:

- What are the most important developments in the drinking water infrastructure of these Dutch cities in the past decades?
- What are the most important drivers, reasons or incentives for these developments and investments? How can these drivers be classified? Can the drivers be classified as internal (within the company itself), external (e.g. policy, climate, behavior, etc.), or transitional (company may have some influence but also depends on external actors).
- Which patterns, trends and drivers with respect to investments in the drinking water infrastructure can be distilled from these analyses?

The driver analysis is the primary goal of this research. The data analysis of historical developments of urban drinking water infrastructures also reveals information on the speed of change of these systems. Information on the speed of change of these systems is considered a secondary goal of this research.

## 1.3 Readers guide

Chapter 2 describes the theoretical concepts of developments of and within socio-technical systems. Chapter 3 described the method used for the driver identification and driver analysis. The chapters 4 – 7 provide an overview of the most important historical investments and occurrences in the four urban drinking water systems. Chapter 8 discusses the driver and system development analysis and chapter 9 contains the general conclusions.

A concurrent study also examined past transitions; four case studies were described, each one focusing on a transition relating to a different part of the drinking water infrastructure (BTO 2015.051 Transitions in the drinking water infrastructure – a retrospective analysis from source to tap). Combined, but from different angles, these two studies seek to derive critical insights and lessons from past transitions that can be used when thinking about and planning for future transitions in drinking water infrastructure. As such, the two studies generate input for the overarching project they are part of, titled ‘drinking water infrastructure of the future’. Although the general focus of this project is indeed on the future of drinking water infrastructure, it is assumed that the future is -at least partly- entwined with and shaped by developments of the past and present, which is precisely why the two studies on past transitions have been undertaken.

The insights and outcomes of this and the other study on past transitions are thus useful in their own respect, but also explicitly inform the subsequent stage of this project, in which plausible future scenarios for the city are construed. These scenarios are used to support drinking water companies in their strategic planning processes, by assessing the robustness of their strategic choices regarding their drinking water infrastructure in light of those scenarios. The implications of the historical driver and transition analysis for the future drinking water infrastructure are described in the overall report which covers the entire project: BTO 2015.048 Strategic planning of drinking water infrastructure: a conceptual framework and building blocks for drinking water companies, see preface for an overview of the reports.

# 2 Theory of transitions in socio-technical systems applied to the drinking water infrastructure

## 2.1 Introduction

Urban water infrastructure is inherently a socio-technical system. Water infrastructure comprises of physical and technological components, such as treatment and distribution infrastructure; and societal components, such as users, operators and managers. The different components are in continuous interaction and subject to pressure of the external environment, resulting in transitions. Brown et al. (2009) described the transitions of the urban water infrastructure over the last 200 years in Australia in six stages. These six stages describe how transitions in urban water have been driven by cumulative socio-political drivers: i) access to and security of supply, ii) public health protection, iii) flood protection, iv) social amenity and environmental protection, v) limits on natural resources and vi) intergenerational equity and resilience to climate change, (Figure 1). Frontrunner countries are currently in the sixth stage. A transition towards water sensitive cities is still taking place. In general, these stages can be identified in different cities. However they may take place during different periods of time, and probably they involve different actors, technologies, etc. As cities develop, urban water managers are being confronted with increasingly complex and multi-faceted challenges, as societal expectations grow and natural resources reach the limits of sustainable exploitation.

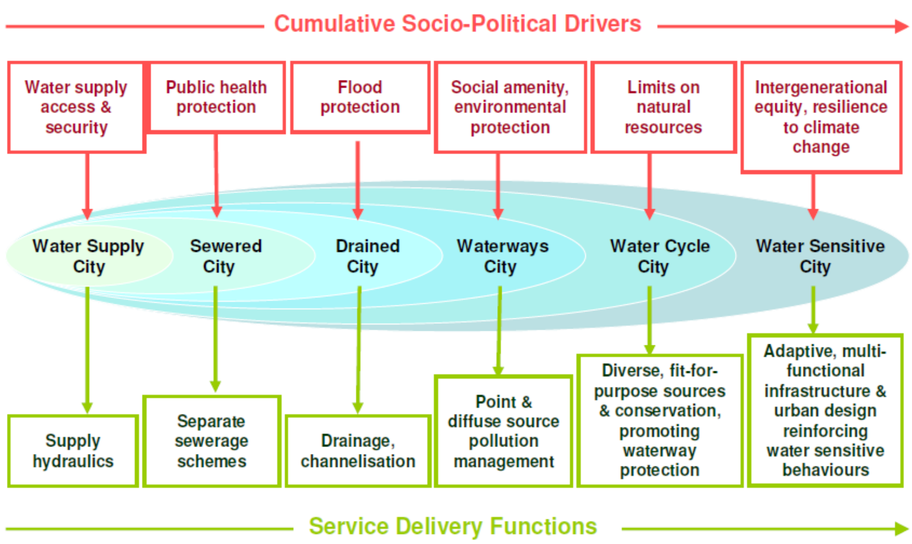



FIGURE 1; TRANSITIONS IN URBAN WATER INFRASTRUCTURE (BROWN ET AL., 2009)

Urban drinking water infrastructure typically includes water collection and storage facilities at source sites, water transport via aqueducts (canals, tunnels and/or pipelines) from source sites to water treatment facilities; water treatment, storage and distribution systems. Each part of the system is subject to different factors that can influence the performance of the system. Figure 2 illustrates this with a simple scheme.

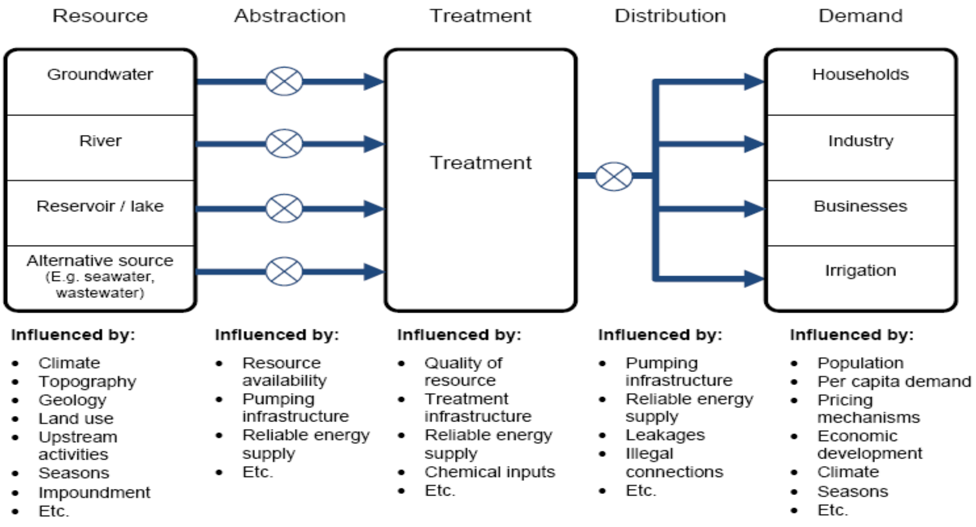



FIGURE 2; SCHEMATIC REPRESENTATION OF THE DRINKING WATER DISTRIBUTION SYSTEM - FROM SOURCE TO TAP - AND INFLUENTIAL FACTORS - DRIVERS, (ICLEI, 201).

## 2.2 The socio-technical regime

Socio-technical systems, such as urban water systems, are typical examples of Complex Adaptive Systems (CAS) where agents tend to act in response to their environment: the built and natural environment; institutional, normative and cultural settings, and the actions of other agents. Within the socio-technical literature, technologies are understood to be embedded within “seamless webs” of social and technical arrangements. These arrangements include patterns of behaviour, social norms, regulatory rules, etc. These structures in which technologies are embedded are termed a socio-technical ‘regime’ (McDowall, 2012).

Socio-technical regimes are dynamically stable and resist change, resulting in inertia and what is often called ‘path dependence’: stable configurations of institutions, techniques, rules, practices and networks that determine the development and the use of technologies along specific trajectories that are difficult and costly to change. Typically, large infrastructure systems, such as drinking water distribution systems, undergo “path dependence”. Socio-technical regimes stabilise existing trajectories in many ways, such as regulations and standards, sunk investments in machines and infrastructures and competences (Papachristos et al., 2013). Structurally, a sociotechnical system comprises of three interrelated elements (Geels, 2004): (i) network of actors and social groups, (ii) formal, cognitive, and normative rules that guide their activities and, (iii) material and technical elements as artefacts and infrastructures. Social groups influence the trajectory of the sociotechnical system and its stability, by adhering to specific sets of rules that constitute the sociotechnical regime under which they operate.

Socio-technical systems display most of the following features:

- Elements of surprise due to the unpredictable nature of the system.
- Emergence of macro-scale properties from micro-scale interactions.
- Irreducibility, or the fact that the system cannot be understood by its parts alone but that the system needs to be viewed in its entirety.
- Self-organisation, or the emergence of order/complexity without inputs from the outside.
- Feedbacks and thresholds; or non-state equilibriums that change over time and which generate dynamic processes with stable and unstable regions.

Previous research has tended to focus on identifying factors that influence residential water consumption (Arbués et al. 2003), rather than on describing and understanding the drivers and dynamics of changing residential water consumption over long periods of time.

## 2.3 Describing transitions of socio-technical systems

Transition is the shift from an initial dynamic equilibrium to a new dynamic equilibrium. In general, a transition can be defined as a long-term, continuous process of change during which a society or a subsystem of society fundamentally changes. Transitions involve innovation in an important part of a societal subsystem. Innovation not only comprises new technology, but also new forms of organization, new practices, new discourses and new insights on global and local concerns (Rotmans, 2003). Transitions occur due to a set of interconnected changes, which reinforce each other but take place in different domains, such as technology, the economy, institutions, ecology, culture, behaviour and belief systems. Geels (2005) refers to these simultaneous changes at different levels as “co-evolution”. Such a study of co-evolution is especially needed to understand innovations at broader aggregation levels and longer time-scales. Transitions are characterised by fast and slow developments as a result of interacting processes.

Diffusion of innovation is in general described with an “S curve”, (Figure 3a). Four stages can be identified: i) a “predevelopment” phase of dynamic equilibrium in which innovators play a major role. ii) A “take off” phase in which early adopters start a process of change in the system. iii) An “acceleration” phase where visible structural changes take place in the system. In this phase collective learning processes, diffusion and embedding processes occur when the majority has adopted the innovation. iv) A “stabilization” phase is achieved, when the speed of social change decreases and a new dynamic equilibrium is reached. However, not all transitions lead to a full adoption; as mentioned, different trends and factors interact and innovation can “lock-in” or “backlash”, (Figure 3b). Therefore, a transition can be characterized by the extend of adoption of the innovation, the rate of change of each phase, and the total time period of change.

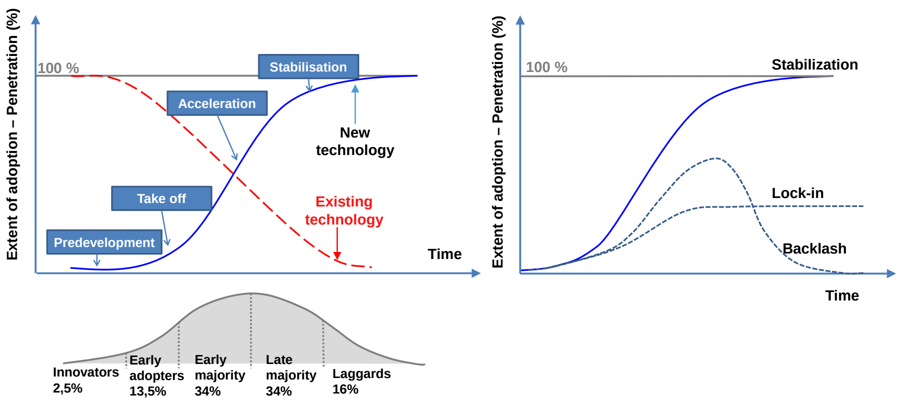



FIGURE 3; SCHEMATIC DESCRIPTION OF TRANSITION TRAJECTORIES A) SUCCESSFUL TRANSITION, B) RESTRICTED OR FAILED TRANSITION TRAJECTORIES (AFTER ROTMANS ET AL., 2001)

## 2.4 The Multi-level perspective

We use the multi-level perspective (MLP) to analyse the socio technical transitions (Geels 2002). The MLP distinguishes three levels: niche-innovations, sociotechnical regimes and sociotechnical landscape (Table 1). A sociotechnical system can be thought of as a set of heterogeneous interlinked elements that fulfil a societal need through technology. In the

MLP, a system transition to a new regime comes as a result of interactions between the three levels. The landscape at the macro level provides long term gradients for the established sociotechnical regime where technologies develop incrementally, and for the niche(s) where radical innovations incubate and proliferate. The dynamic stability of the regime can be perturbed by innovations that develop in niches, pressures from the landscape that act on the regime, or from the build-up of internal regime tensions. Social groups within the regime can mount an endogenous response to absorb the pressures and/or niche innovations. In some cases however, this response to persistent problems/pressures, is not sufficient and a system transition to a completely new regime takes place. In a transition, the prevailing attitudes, practices of technology production, and its use in the system are gradually substituted by new ones that originate in niches – novel small scale sociotechnical systems (Schot and Geels 2007).

TABLE 1; DESCRIPTION OF THE THREE LEVELS OF THE MLP (GEELS 2002)

| Level | Speed of change | Characteristics |
|---|---|---|
| Macro level (landscape) | generally slow (decades and generations) | Incorporates dominant cultures and worldviews, as well as the natural environment and large material systems such as cities. Change is generally slow and often beyond the direct influence of individual actors or organisations, and might include changes in population dynamics, political models, macroeconomics or environmental conditions. |
| Meso level (regime) | Change is thought to move in decades. | Regimes are broad communities of social groups with aligned activities who operate according to formal and informal rules and norms, which are maintained to deliver economic and social outcomes. |
| Micro level (niche) | Generally rapid, can occur in months, years. | Niches provide a protective space for radical products, processes, and technologies to emerge substantially different from status quo. Innovations are fostered and protected from the dominant regime by a small network of dedicated actors, sometimes operating outside of the dominant regime. |

As shown in Figure 4, urban transitions are the result of mutual interactions between the three levels and within regimes. In an urban area several transitions occur simultaneously and each transition can be characterised according to the initial status of the regime, landscape and niches, driving forces, and stakeholders involved. It is important to keep in mind that while transitions occur in the “socio-technical regime”, the landscape also changes and that new niches are being formed. Transitions are not stand alone events but they can reinforce or disrupt other parallel transitions. Moreover, the starting of a transition can be a technological development (niche), changes in society (regime) or form of landscape (new environmental policies, economic crisis, etc.). Influential actors, resources, processes and events, can reside in niches(s) and regime(s) or even outside the system, in the landscape.

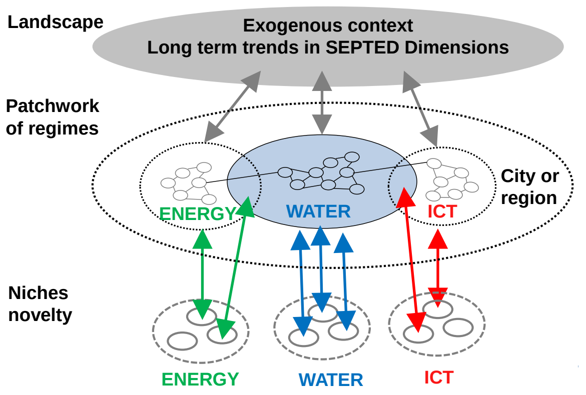
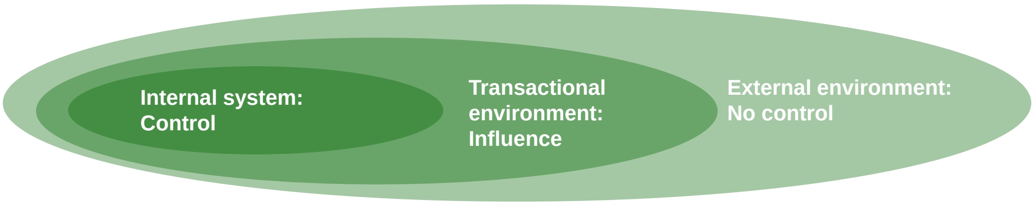



FIGURE 4; SCHEMATIC REPRESENTATION OF THE MULTI-LEVEL PERSPECTIVE (MLP) FOR THIS STUDY, INTERACTIONS BETWEEN THE INFRASTRUCTURE REGIMES IN THE CITY AND THE NICHES AND LANDSCAPE.

Geels (2005) used the multi-level perspective to describe the transition in water supply and personal hygiene in the Netherlands (1850-1930). This transition is a good example of coevolution of technology and society, involving technological innovations, such as piped water infrastructure, soap, toilets, baths, as well as cultural, political, economic and behavioural changes. Piped water gave rise to a new regime around water supply, giving rise to new social groups (water companies and their branch organization), new knowledge and new regulations.

## 2.5 Sphere of influence

The sphere of influence is a concept which is often used to delineate the boundary between the internal (focus) and the external system. The internal system is thus defined as the spatial and conceptual realm over which the organization has significant cultural, economic, political, or physical control. On the other hand, the external system is the rest of the world, out of the control of the organization. However in the external system, there is a “grey area”, which is referred to as the transactional environment. In the transactional environment, the organization does not have direct control but may, for example through collaboration or lobbying, influence other organisations or individuals to change circumstances in a certain way (Figure 5). Both the transactional environment and the internal system are embedded in the external system.




**Internal system**: aspects of water infrastructure that water company controls

**Transactional environment**: Water companies are also dependent on strategies, agendas of other actors. No control, but potential influence

**External system:** developments and trends impacting on WI where water company has no control over

FIGURE 5; DEFINING SYSTEM BOUNDARIES FOR WATER INFRASTRUCTURE (WI) (AFTER GHARAJEDAGHI, 1999)

The systems (internal and external) in Figure 5 are not static but dynamic: both concerning the location of the system boundaries and the interaction between the internal and the external systems. Planning refers to making decisions to take actions directed at changing or maintaining certain properties of the Internal Systems and the Transactional Space. At the one hand, this directed change may be proactive by anticipating changes in the External Systems and Transactional Space, changes that pose threats or create opportunities for the Internal Systems. At the other hand, this directed change may be reactive by responding to the changes once they have occurred. Some planning strategies require flexibility but as the costs of adaptation increase, as with investments in infrastructure, so too do the benefits of preparedness.

Transitions can be seen as evolutionary processes that mark possible development pathways, of which the direction and pace could be influenced by slowing down or accelerating phases (Figure 6). Therefore, the question that arises is: to what extent and in what manner can these broad societal innovation processes, such as transitions, be managed or steered? Transitions on urban water management cannot be managed by traditional practices (i.e. command-control), but instead require processes of influence (i.e. steering, facilitation and coordination). Therefore, identifying the sphere of influence is crucial to steer future transitions, by identifying potential partnerships. Transition management can be characterized as a joint search and learn process though envisioning, experimentation, and organizing multi-actor coalitions of frontrunners.

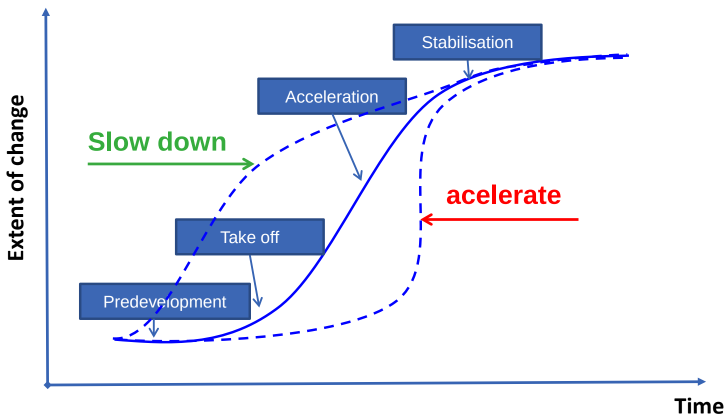



FIGURE 6; POSSIBLE DEVELOPMENT PATHWAYS IN A TRANSITION PROCESS

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# 3 Methodology

## 3.1 Approach and methodology

This research primary focusses on identifying the most important developments of the drinking water infrastructure regarding the assets of the primary process of drinking water production and distribution. In order to gather information on the historical developments and investments of the four Dutch urban areas of Amsterdam, Groningen, Arnhem-Nijmegen, and Maastricht, a literature review was conducted and drinking water professionals were interviewed.

The literature review in most cases comprised professional magazines, internal drinking water company reports, KIWA and KWR reports, and books that were published by the municipality or the drinking water company for the occasion of an anniversary of the water company.

The interviews were conducted with experts of the four concerning drinking water companies: Waternet for Amsterdam, WML for Maastricht, Vitens for Arnhem and Nijmegen and Waterbedrijf Groningen for Groningen. Each interview was conducted with two or three people per company, and additional information was gathered through e-mail or by telephone, during the period of November 2013 – January 2014. The texts governing the developments, changes and states of the drinking water infrastructures of the four urban areas were verified by the people who were interviewed.

Although the specific focus is the last five decades (~ 1960 – 2014), it was decided to include the information on investments prior to 1960s, since these early investments are in many cases greatly influencing the developments of the last five decades due to path dependence.

The drivers were identified from literature available on the (development of) assets of the four urban areas and interviews with the experts of the drinking water companies. This information was summarized in a description of the infrastructural developments, or in some cases the states, of each urban area. We focused on the following physical assets: the water source, the water catchment area, water intake and abstraction and the water wells, the drinking water treatment facilities and large transport pipeline and storage systems. It was not attempted to make a complete inventory of every investment. For instance, assets such as money and people were not included in the inventory. The description of developments include the asset of concern, the type of change the investment induced, and the reasons or incentives behind the investment.

Information on the type of investment, the year of investment, the driver behind the investment, the classification of the driver and the sphere of influence was deducted from these descriptions and summarized in tables. This information was analyzed according a semi-quantitative approach:

- All identified reasons and incentives for investments were clustered or classified in a limited number of drivers.
- The occurrence of these drivers was analyzed for each city, and for three time periods. Initially, we planned to focus on the past five decades (~ 1960 – 2014), and it was decided to divide this period into two nearly equally lasting sub-periods (1960 – 1985

and 1985 – 2014). It was decided to include information on the period prior to 1960 as well, however this period was considered as a whole.

- Changes in the spheres of influence were studied by analyzing the occurrence of internal, transactional and external forces behind the drinking water infrastructure investments.

# 4 Groningen

## 4.1 Summary infrastructural development Groningen

The first surface water facility of Groningen was built in 1880 and is still in use. This facility has been adapted several times between 1880 and 2012. The source changed from surface water only, to mixed treatment of surface- and groundwater, to groundwater only, and since the early 1970s both surface water and groundwater are used and treated in a separate configuration. The treatment of the surface water was gradually expanded, in order to adapt to variations of the source water quality and meet more stringent water quality standards, because of technological development and in order to meet the growing water demand. In the beginning of the 20th century, the city had two water companies (a private enterprise and the municipality); some districts had two distribution networks. At the end of the 20$^{th}$ century the city of Groningen had grown, but the water production of the municipality stagnated because the municipality got 'isolated' by the provincial water company for which the municipality could not grow further, and the water consumption in the city had stagnated. Shortly after, the municipality and the provincial water company merged. (in 1998) The transport capacity of the source water and the drinking water was expanded a couple of times due to the increasing drinking water demand and requirements on security of supply.

## 4.2 The first facilities in the first decades: surface water treatment at De Punt

The production facility of the city of Groningen 'De Punt' was built in 1880, in the village of Glimmen (council of Haren), approximately 9 km south of the city of Groningen. Around 1875, it was concluded that drinking water production was hardly possible inside the city because of water quality issues, and it was advised to search for sources outside the city. Three possible sources were assessed for the applicability for centralized drinking water production. The water quality of the two lakes (Zuidlaardermeer and Leekstermeer) was not adequate, because of the presence of peat soil. A small river, the Drenthsche Aa, turned out to be suitable (water quality and quantity). Its water originates from higher grounds, at the Drents plateau, north from the city of Assen.

It was decided to subtract the river water not too close to the city because of urban activities. Therefore a location 10 km away was selected for extraction, where shipping traffic was not possible and the land upstream was sparsely populated. The raw water contained some color and iron. The source was exposed to compounds that could form a threat to public health, hence the treatment of the water has always been important. The water was pretreated with the coagulant alum in order to remove color and iron (flocculation and sedimentation). The post-treatment comprised of slow sand filtration for removal of bacteria. Because the water demand rose between 1880 – 1935, the facility was expanded to nine sedimentation reservoirs and five filters. In 1881, a water tower with a capacity of 700 $m^3$ was built at the Hereweg (the South tower, Figure 7). This water tower was dismantled in 1970. The canal in the city center (Verbindingskanaal) was crossed by means of sag pipes.

The capacity of the raw water transport pipeline between the intake and the treatment plant was expanded. Also, the drinking water transport to the city was expanded with an additional 400 mm pipe next to the existing 250 mm pipeline. Because of customer complaints regarding color, the alum treatment was optimized several times. Another explanation for the complaints regarding color and taste is the inner pipe bitumen coating. The taste complaints were not solved at that time.

In 1923, rapid sand filtration was installed at De Punt between the sedimentation and the slow sand filtration, to improve water quality of the influent to the final filtration step (removal of turbidity). In order to meet the growing water demand, it was required to increase the filtration capacity. The filtration velocities were tested at pilot scale, for different water quality types. They found that an increase of the slow filters capacity was possible under the condition that the pretreatment was sufficient, for which the process configuration was adapted.

### 4.3 Early 20th century: two drinking water companies in the city of Groningen

In 1882 – 1918, the private enterprise “N.V. De Groninger Waterleiding” was responsible for the water supply of the city of Groningen. The city council and the private company had many serious disagreements and the city decided to establish its own municipal water company, the Gemeentelijke Waterleiding Groningen (GWG), around 1910. The first disagreements start with the break out of cholera, during which the council wanted to close down wells in the city and place drinking water stand-pipes at the distribution network. Although the city council was eager to acquire the assets from the private company prior to the ending of the concession, no agreement was reached.

In 1911, the city council (GWG) decided to construct a municipal groundwater facility (extraction and treatment) in the village of Haren, as well as a water tower (West tower)[1] in the city of Groningen. In 1925, the capacity was expanded with a second reservoir of 800 $m^3$. The water tower was severely damaged in the World War II, and it was reconstructed in 1947. This West tower is still in use in beginning of the 21st century but will be closed in 2014 (Figure 7).

Hence, in the beginning of the 20th century the city of Groningen had two drinking water companies. The municipality of Groningen supplied water to the city buildings, but also households could decide to purchase the water from the city. In some parts the city had two distribution networks. In 1918, the municipality of Groningen acquired the assets of the privately held drinking water company, after many court cases and negotiations.

### 4.4 The 1930s: groundwater treatment next to surface water

Around 1930, six groundwater wells were constructed. It was found that groundwater was abundant and of good quality. Tests were performed to find the best way for the combined treating of surface- and groundwater. It was found that the mixed treatment of both sources was possible without usage of alum dosage. However, an additional filtration step was required. In 1935, the treatment comprised of mixing of surface and ground water, sedimentation, filtration (course sand), aeration, filtration (sand), and slow sand filtration. The alum could be left out because the presence of iron in the groundwater overtook its function while mixed with the surface water. In the meantime, the slow sand filtration step was covered in order to stop the growth of algae and increase the time between cleaning. In those days, another facility adaptation was planned, namely the construction of a de-acidification step (aeration and lime) in order to improve the removal of iron and color.

In the 1930s, two large drinking water reservoirs were built, with a total capacity of 10.000 $m^3$. In 2014, these reservoirs are still in use and store the drinking water that is produced out of groundwater. In this period, the water was additionally disinfected with ozone. The ozone was probably abandoned a few decades later (estimate: in the 1960s), probably

[1] Construction water tower at the Herman Colleniusstraat, with a capacity of 1000 $m^3$.

because the process could be controlled well after the covering of the slow sand filters and chlorination was introduced.

The ratio between surface and groundwater was tuned to the value of total hardness of the drinking water supplied to the city by the groundwater facility of Haren.

### 4.5 1960s: reduction of surface water usage

The treatment of the mixed water lasts until 1960. At this point, the river The Drentsche Aa is polluted and adaptation of the treatment process is required. The amount of water extracted from the river had been reduced to a minimum through these years, therefore it was decided to entirely stop the treating of surface water. In 1971, the facility of De Punt was significantly adapted.

In this period, provincial policy makers made successful efforts to improve the surface water quality. Because this river had a drinking water function, there had always been efforts to protect its quality well. Certain industries were not allowed to discharge their wastewater onto this river. Stricter rules concerning agricultural land usage for the upstream area were applied. In 1960, the annual amount of surface water used was cut down to 0,4 million $m^3$/y, and in 1973 this amount was restored to 5 million $m^3$/y, accounting for one third of the drinking water production.

In the 1970s, the treatment of the surface water during low temperatures in the winter was improved by use of additional chemicals. Due to the constant improvement of the treatment process, the company is less and less dependent of the surface water quality changes. For instance, strong rainfall, pollution by sand used along road works, and large amounts of melting water repeatedly show the vulnerability of relying on the small river.

Between the World War II and the 1970s, the number of groundwater wells at De Punt gradually expanded due to the search for new sources: firstly eight, later in the 1960s ten additional, and in the late 1970s another three were built.

Also the Haren facility was adapted and expanded between the 1930s and the 1960s. In 1935, an additional sequential filtration step (pretreatment) was constructed at this facility. The filters were adapted prior to the war. The facility was thoroughly renovated in 1959, and in this period the groundwater extraction capacity was significantly increased with another sixteen wells in order to compensate for the reduced capacity of De Punt, which was renovated at that time. Finally, the Haren site had 38 groundwater wells, producing water at the peak demand during daytime. The production capacity was limited (only production during daytime) in order to prevent extraction of groundwater with high salt concentrations. The Haren facility accounts for 10% of the total water demand. The capacity of the wells was limited because of the raw water quality.

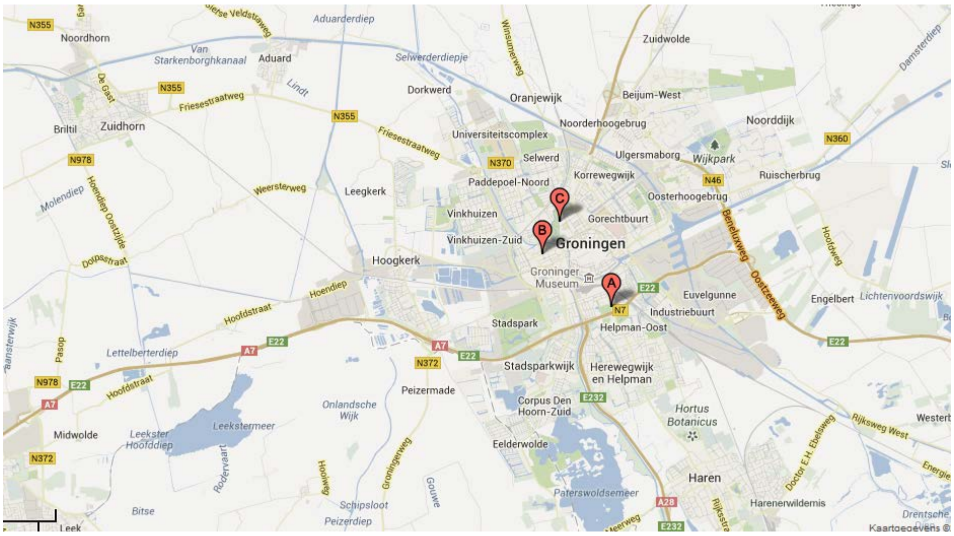


FIGURE 7; WATER TOWERS IN THE CITY OF GRONINGEN (A = SOUTH TOWER; B = WEST TOWER; C = NORTH TOWER).

## 4.6 Provincial water company WAPROG

In 1930, the province of Groningen established the drinking water company “WAPROG” (N.V. Waterleidingmaatschappij voor de Provincie Groningen). They started in 1934 and would supply the provincial area except the city of Groningen. The company was established because of public health, inspired by the successful experiences of the city of Groningen. The provincial company built their first groundwater facility in the village of Onnen (council of Haren). Most councils in the province, except Groningen and Haren, were shareholder. In the early 1950s, the second production facility was built in the west of the province. This was the groundwater facility Nietap. A large area of the province could be served with water from these two facilities.

In the mid-1960s, De Groeve facility was started (groundwater), mainly because a strong increase of the water demand was expected in view of the development of the port in the town of Delfzijl. Finally, the fourth groundwater facility was built in Sellingen in 1971. The facility was built for 3 $Mm^3$/y but plans were made for growth up to 7 $Mm^3$/y to meet the expected demand.

These groundwater facilities comprised of aeration and two sequential rapid sand filtration steps. In the 1970s, the treatment installations of De Groeve, Nietap and Onnen were prepared for the expected water demand rise and adapted: Onnen got additional filtration capacity and the elder filtration was broken down, and De Groeve and Nietap got an additional filtration building. The energy crisis and the governmental campaign to save water caused the water demand to stop rising (Agudelo-Vera et al., 2015). After Sellingen, no more additional production facilities were built in the province. The location of the production facilities is illustrated by Figure 8.

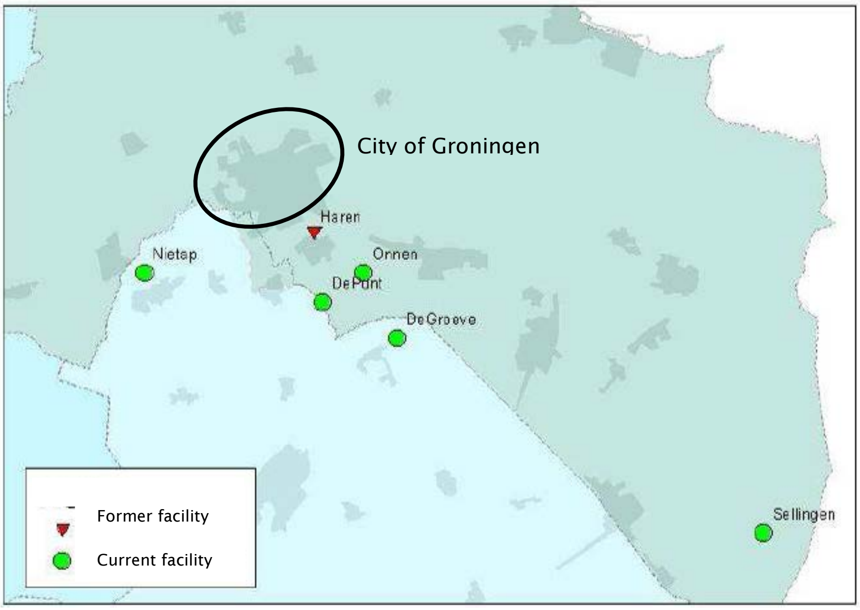


FIGURE 8; OVERVIEW OF THE FACILITIES OF GRONINGEN IN 2014 (LEUNK, 2012)

## 4.7 Treatment of De Punt after 1970

The renovation of De Punt in the 1960s was initiated by the need for an increased extraction, purification and pumping capacity. Also, the facility adapted its own energy supply. The renovation was completed in 1971. During this period, the water company also starts adding fluoride to the drinking water, which was believed to be favorable for dental care. However, the addition of fluoride was prohibited by law a few years later (1974), after many action groups demonstrated against this type of involuntary medical care.

After the renovation of De Punt was finalized, the GWG researched the possibilities of membrane filtration and deep infiltration:

Ultrafiltration was investigated in the 1990s for surface water treatment (replacing sand filtration with ultrafiltration), in order to anticipate the changing raw water quality, the developments of the quality standards and the availability of new technologies.

In order to secure the drinking water supply of the cities of Groningen, Haren and Eelde, the possibilities of infiltration at the Haren site were investigated in the 1970s. Surface water and groundwater extracted at De Punt could successfully be infiltrated. The infiltration project led to an increased surface water usage, which was stimulated by governmental policies (reduce dry-out of vulnerable soils), and could also prevent the possible upconing of brackish water at the Haren site. The full scale infiltration was constructed at Weerdebras in the 1990s and attained an annual capacity of 2,5 $Mm^3/y$. Besides the abovementioned quantitative advantages of infiltration, also several water quality improvements occur.

In the 1980s, the sedimentation reservoirs were adapted towards coagulation reservoirs. First, pine-trees were placed next to the basins in order to reduce the wind speed and inhibit mixing of the water. Later, the coagulation reservoirs got covered to avoid outdoor influences (contamination, weather influences). These investment in the coagulation system were only performed after it got clear that surface water still was a solid option for drinking water production. This notion relied on the improvement of the surface water quality due to waste water discharge regulations and agreements made on the reduction of groundwater usage.

In the period the surface water and groundwater was mixed prior to further treatment, sprayers were installed to aerate the water properly. Later, the amount of groundwater used increased significantly and it was decided to treat the surface water and groundwater separately in the 1960s. After the treating got separated, the surface water got filtered in the building having these sprayers. As a consequence, the surface water got aerated although this treatment was needless. The sprayers were only removed some decades later.

In 1985, De Punt was expanded with activated carbon filtration because of the presence of pesticides in the raw water. In this period, many surface water treatment plants were adapted for pesticide removal. The activated carbon media was installed in the existing construction built in 1937, by replacing the first sand filtration step. This building was for treating the surface water only since the 1960s. It was known that the placement directly after the coagulation was not the ideal position in the process configuration, but at the time it was the best option given the technical and financial boundaries.

In the early 1980s, the surface water provides 40% of the drinking water, and the groundwater of De Punt and Haren are providing the rest. The river shows large flow variations, besides quality variations, and the reservoir hardly has storage capacity. Therefore, De Punt will need to rely on groundwater as well, next to surface water.

In 1988 the post chlorination stopped at De Punt, after it was discovered that the addition of chlorine would lead to the formation of harmful byproducts, and after it was shown that distribution without chlorine is well possible without adverse public health effects under strict conditions.

The water quality of the river Drentsche Aa showed large quality variations, and pesticides were detected. Therefore, it was decided to dig a storage reservoir with a capacity of 30 – 60 days in the mid-1990s. Its main function is to guarantee a more constant influent quality by the mixing of the surface water and smoothing of the quality.

### 4.8 1980 – 2000: Service area isolation and demand stagnation of municipality, and merger to Waterbedrijf Groningen

In the 20$^{th}$ century, the city of Groningen had grown, and some districts got incorporated by the city. These towns were served by the WAPROG. Because of this, the provincial and the municipal company started to get many disagreements on the water services concession. The council of Groningen annexed certain villages which were served by the provincial WAPROG, and they assumed that the concession would pass over to the municipality. It was decided in court that WAPROG contained the right to supply some of the districts of the city of Groningen. Because of stagnation of the service area as well as the stagnation of water demand, the water production of the municipality of Groningen got fixed at a maximum. In the 1980s and 1990s, these conflicts between GWG and WAPROG got to be described as a ‘water war’ by some media. The fixed demand and the expected investment costs would lead to a sharp rise of the water price of the GWG.

In the 1980s, the Drinking Water Decree stated that water companies with less than 100.000 connections should join or merge with larger companies, which was the case for the city of Groningen. Different merger alternatives were studied by various drinking water companies in order to obtain larger scale companies. The plans included several options with the provinces of Groningen, Friesland and Drenthe, the private company Nuon, and the city of

Groningen. In 1998, the GWG and WAPROG merged to the current drinking water company 'Waterbedrijf Groningen'.

### 4.9 2000 – 2012: Renovating De Punt facility after the merger

After the merger, the research of membrane filtration for application at De Punt was stopped. Some new colleagues questioned the necessity of the surface water treatment plant, or at least were in favor of groundwater usage. Also, the application of membrane filtration would be too expensive for the surface water treatment, while the surface water (municipality) already was more expensive than the groundwater treatment (province). A few years later, it was decided to thoroughly renovate De Punt. Various reasons led to the reinvesting in the surface water treatment plant: i) the agreement between water companies and policy makers to reduce the groundwater extraction, ii) all efforts aimed for improving the surface water quality had been successful and also led to advantageous spin-off effects for the natural environment, iii) the production capacity of 7 $Mm^3$/y from surface water was required to meet the annual water demand.

In this period, the infiltration of water was ceased because of costs, capacity and security of supply. The surface water used to be pretreated prior to infiltration. After infiltration and extraction, it had to treated again in the groundwater treatment facility, for which the amount of actual groundwater to be treated got limited. By treating the surface water without infiltration, the capacity for treatment of groundwater has increased.

The groundwater facility of Haren was closed down in 2011, because of its small capacity, the need for renovation and the preference of surface water. Currently, it is considered to shut down the facility of Sellingen as well, because of similar arguments and the option to purchase water from the neighbor drinking water company.

The UV disinfection was installed around 2005, after it turned out that the water had been contaminated with Campylobacter. The harmful bacteria originate from the presence of birds around the reservoir during winter time. The water was chlorinated for one year, until the UV-installation was started up. Initially, the UV installation was placed as the final treatment step. However, it was shown that in this particular case the biological stability would decrease because of the presence of UV. Therefore  the UV installation was placed prior to the slow sand filtration.

The renovation of De Punt was completed in 2012. The surface water and groundwater have their separate treatment processes. The current process configuration for surface water treatment has a reservoir, coagulation and sedimentation (with added chemicals), double layer filtration, activated carbon filtration, UV disinfection and slow sand filtration. The groundwater is treated with aeration and sand filtration, and has a capacity of 4 $Mm^3$/y. Also, 1,5 $Mm^3$/y of water is purchased from the neighboring water company of Drenthe (WMD). De Punt has been built in a redundant way, and is able to produce 70% of the maximum peak, even when halve of the treatment has been shut down.

During the renovation, one of the large buildings at De Punt site was entirely removed (in 2011). This building was constructed in 1937, having an aeration an two filtration steps, but it never functioned properly because of its inadequate design. The new double layer filtration and the activated carbon filtration are constructed at the spot at which the sedimentation basins were formerly located.

### 4.10 Transport pipelines, distribution network and storage

Initially, two transport pipes connected De Punt to the city. In 1937, a 750 mm cast iron transport pipeline was constructed. In 1994, a 700 mm existing transport pipeline was relined with PVC. This transport pipeline got repaired after leakage caused severe problems at the A28 highway. Together with the 1992 transport pipeline from De Punt to the city, the distribution from De Punt to the city is secured by three pipelines. The eldest pipelines are decoupled in the meantime. In fact, the supply would be reliable with two pipelines as well. The town of Haren grew in the 1960s in the direction of the existing 750 mm pipeline. The pipeline has never failed, but failure would lead to damage to the buildings in its surroundings, because the areas got denser populated over time. Plans exist to expand the A28 highway from four to six lanes, for which the PVC transport pipeline will have to be removed. In case this project proceeds, the 750 mm transport pipeline and the pipeline next to the highway will be replaced by one new 900 mm pipeline. The risk of failure of the 750 mm pipeline might act as an additional argument in the eventual replacement projects.

In the design of the water transport network from De Punt facility to the city, redundancy was taken into account right away in order to provide a reliable water supply. Two more large transport pipes were constructed beneath the canal. Also, a circular pipe system was part of the design. Due to the increasing water demand it was harder to keep the water pressurized. Therefore, a second circular piping system around the city was finished in 1954. In the 1970s, plans were made for the development of a third ring system, and part of this network plan was constructed. This ring was not finished because of the stagnation of the water demand. The city canals are mostly crossed by sag pipes.

In 1969, the city grew significantly because the villages of Hoogkerk (south west from the city) and Noorddijk (north east from city) were annexed by the city, as well as the villages of Beijum and Leewenborg (north east from city). These districts were served by the provincial water company WAPROG, despite the annexation. In 1988, both the WAPROG and GWG constructed decent transport pipelines in the region of Hoogkerk, because the relationship between the companies did not allow for cooperation. For the same reason, no connections between the city and the provincial network existed until after the merger.

In 1908, N.V. De Groninger Waterleiding built its second water tower at the Noorderbinnensingel (North tower), which is not in use anymore. The construction was initiated by the building of the academic hospital in this area. Recently, the West water tower has been shut down (2014) and sold. The water towers are mainly closed because the storage capacity is installed at the production sites and the storage capacity of water towers is limited.

### 4.11 Distribution network after merger

After the merger, the production and distribution system were integrally analyzed for the reliability of supply, and the city network and the provincial network got connected. Pressure reducers are required because historically the city was operated at lower pressures than the province. The rational behind this probably was that higher pressures were required in the provincial area because the production facilities were situated on the southern side of the province only and the north side needed sufficient pressure. The city was kept pressurized by water towers and its production facility was situated more closely to the city. The provincial network is an open design, that is whenever one of the production facility fails the water supply is taken over by another facility.

## 4.12 Water demand forecasting

In the 1970s, it was expected that an additional annual capacity of several tens of millions $m^3$ was needed to serve the newly developed port 'The Eemshaven', the town of Delfzijl and the surrounding industries such as Akzo in the north of the province. This was one of the arguments for WAPROG to develop its facility De Groeve.

Also, in this period many research and plans were aiming for the development of additional surface water storage and treatment in this region, such as the creation of freshwater collection basins near Leek which would contain surplus of rainwater and IJssel lake water. These collection reservoirs were never built.

A 500 mm transport pipe was laid to the port. In the 1970s the provincial company forecasted a groundwater usage of 80 $Mm^3/y$, but it turned out that the groundwater extraction stabilized to an annual usage of about 50 $Mm^3/y$. The growth of the port developed slower than expected, therefore only small volumes of water were transported for a long period. The port develops faster since the beginning of the 21st century, and future plans comprise the start-up of a couple of energy plants and data centers. This might lead to additional required (industrial) water capacity. Also, in the period of expected growth, the WAPROG purchased land near the Damsterdiep canal (Groningen – Appingedam) to extract surface water for additional treatment. It has never been necessary to further develop this surface water extraction site.

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# 5 Arnhem – Nijmegen

## 5.1 Summary infrastructural development Arnhem – Nijmegen

Both the cities of Arnhem and Nijmegen were served by a municipality for a long time. Groundwater is abundant is this region and both cities had one or two treatment facilities for most of the time. Due to the geological situation, both cities have storage reservoirs in the higher parts of the city. The drinking water treatment was relatively uncomplicated, comprising aeration, filtration and conditioning, except for the facility in the city center of Nijmegen which was facing groundwater pollution at the end of the 20th century. The municipalities were acquired by a private enterprise at the end of the 20th century. The municipalities got 'isolated' by the provincial water company. After the merger of the city water companies and the provincial water company, the water supply plans were considered in an integral way on a larger scale. The increase of the scale of production, the desired reduction of groundwater extraction in natural reserves and the hardness of the water of facilities led to the shutting down of certain smaller scale facilities, clustering towards larger scale facilities and larger scale transport of drinking water towards the city and from the city towards rural areas.

An overview of the urban area of Arnhem and Nijmegen and the drinking water treatment facilities (status 2014) is presented in Figure 9.

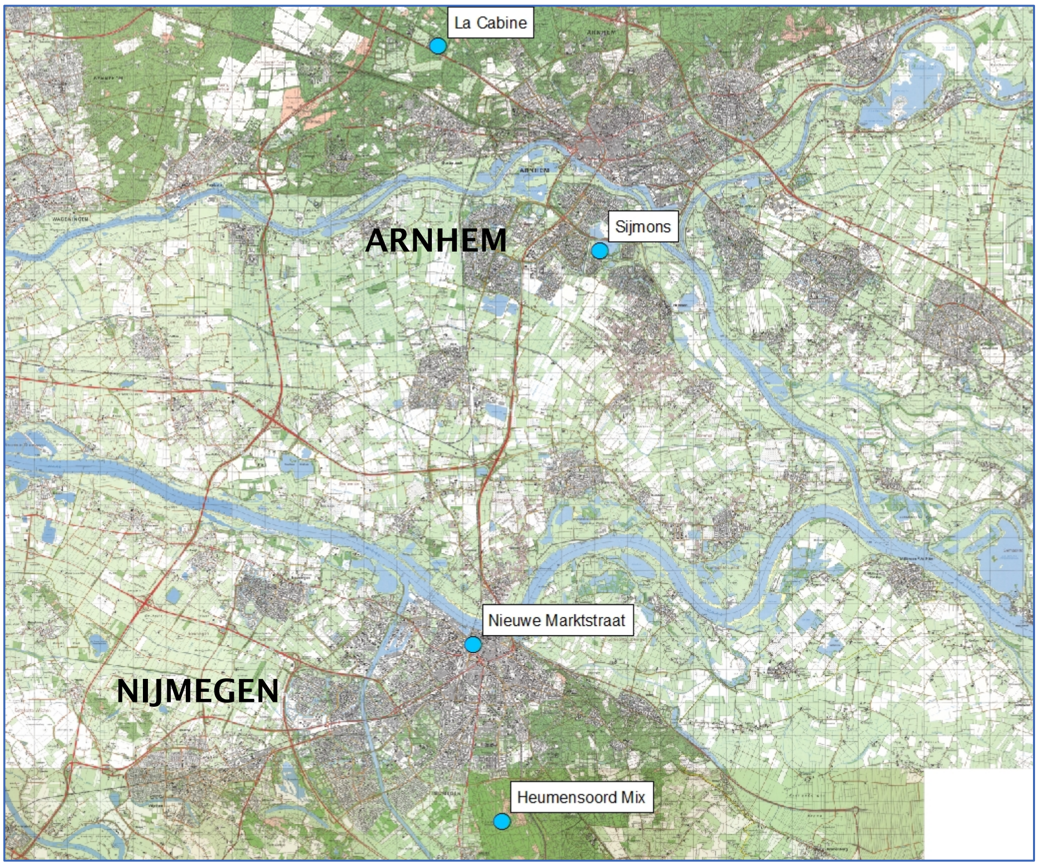


FIGURE 9; OVERVIEW OF URBAN AREA AND PRODUCTION FACILITIES OF ARNHEM AND NIJMEGEN IN 2014.

## 5.2 Arnhem

The drinking water company of Arnhem (NV Arnhemsche Waterleiding-Maatschappij) was established in 1885 as a private initiative. This company arose from the Belgium company from Liege, that is the Compagnie General des Conduites d'Eau.

### 5.2.1 The first facilities

Arnhem has always used groundwater for their drinking water supply. The first facilities (1885) were the catchment area at Arnhemse Broek, the high reservoir at Hommelseweg (1500 $m^3$) and a pumping facility at Westervoortsedijk. The reservoir was built rather than a water tower because the construction of a water tower would be too expensive. The groundwater runs from the hilly north side of the city towards the river Rhine in the south. A second reservoir was built in 1893, at the Bakenbergseweg in order to remain the water pressurized. This reservoir was a water tower with a storage capacity of 200 $m^3$.

### 5.2.2 The second treatment facility

The water demand was ever increasing, leading to unacceptable pressure losses, especially in the higher parts of the city. For this reason, a new pumping station was built. The new catchment area as well as the pumping station were started up in 1909, near the Amsterdamseweg in the north of Arnhem. This became the facility named 'La Cabine'. The extracted water did not need any treatment since it was of excellent quality, originating from the natural reserve area 'The Veluwe' situated north of the city. Shortly after, the first facility at Westervoortsedijk started to produce iron containing water, leading to customer complaints. Therefore, it became a back-up facility and finally it was shut down. The water tower 'De Steenen Tafel' in the north-west of the city was built in 1928 to restore the required pressure, again.

### 5.2.3 The 1940s and 1950s: municipality, World War II, deeper extraction and adapted distribution

In 1939, the city of Arnhem acquired the concession for the exploitation of the drinking water company, and the municipality GEWAB (GEmeentelijk WAterBedrijf) was established. The acquisition by the city had been postponed till 1939 because of its financial situation. The acquisition process found quite some resistance in the city council, because of the uncertainties about the value of the assets.

During the second world war, the south part of Arnhem, below the river Rhine, was shut down from drinking water because the Rhine bridge and it bridge transport pipeline were destroyed in 1940. It was repaired later, and in the beginning of the 21$^{st}$ century the bridge transport pipeline was closed down because of its poor condition. The interruption of the water supply was solved with the construction of the temporary facility at the Melkweg, south from the river.

Historically, the city of Arnhem had developed north from the river Rhine. Unlike Nijmegen, the city had also grown to the other side of the river quite some time ago, although the city council had to motivate people to inhabit the south part. Expansion of the city to the north was limited due to the presence of the nature reserve of the Veluwe. In the 1940s, two sag pipes are constructed to connect both sides of the river. One of the transport pipelines was left damaged during construction. In 2014, both parts of the city are connected through three sag pipes.

The adaptation of the airport in the north of the city was forced by the German invaders during the war. It led to the installation of a transport pipeline and an additional booster station (Schelmseweg).

In 1940, the districts in the north west of the city (Hoogkamp, Sterrenberg) were no longer served via Bakenbergseweg, but instead a booster station was installed at the Amsterdamseweg. The water tower 'De Steenen Tafel' was damaged during the war. Also, during the Battle of Arnhem, the treatment facility of La Cabine is damaged, which led to a temporary stagnation of the water supply.

The capacity of the reservoir at Hommelseweg is expanded in the early 1950s, with a second reservoir with a capacity of 3000 $m^3$. Also, this facility is expanded with a booster station, replacing the booster at Apeldoornseweg. Until 1950, the water was extracted with help of vacuum pumps. Hereafter, the extraction of the water was moved from phreatic to deeper aquifers. The facility of La Cabine was completely replaced by new constructions in 1953 and its operation is automated in 1958. Lime was added to the drinking water in the storage reservoir for conditioning purposes.

### 5.2.4 Growing water demand, start-up of new facility

In 1968, La Cabine got a temporary permit to extract groundwater from a deep aquifer. Four wells were needed to meet the required water demand.

The booster installation Bakenbergseweg was replaced by a new installation at the Teerplaats (Zypendaal) in 1959. In 1978, two km east from La Cabine, a new booster station (Dieckman) was built to divide the water from La Cabine in a better way between the different pressure zones. Since then the Teerplaats and Waterberg boosters function as back-up.

The capacity of La Cabine lacked the required water demand. Therefore, the second production facility of Arnhem, Sijmons, was built in 1980. The Sijmons facility is situated in the south of Arnhem. The reason to move the groundwater extraction to the south of city was to spare the groundwater of the nature reserve of the Veluwe area. The facility was expanded from 3 to 5,5 $Mm^3/y$ because of the increased water demand. In the meantime, the Sijmons facility entirely got surrounded by the buildings of the city. The facility of Sijmons produces the base load, and La Cabine produces the peak demand.

### 5.2.5 Renovations and adaptations after the 1980s

The facility of La Cabine was renovated in 1985, after a period of thirty years of intensive usage. Part of the extracted groundwater has low values of hardness and is aggressive to calcium carbonate. This water needs to be conditioned with marble filtration in order to protect cement distribution pipelines against damaging. The rest of the groundwater is untreated. Hence, the historical development of the treatment plant of La Cabine is as follows:

- Shallow groundwater without any treatment;
- Deeper groundwater without treatment, but with the adding of lime;
- Deeper groundwater, partly treated with marble filtration since 1985, for conditioning purposes (reduce damaging of transport pipeline materials), partly treated with sand filtration since the 1970s to remove iron, and partly untreated.

In the twentieth century, the catchment of La Cabine was gradually expanded, and the extraction moved to the deeper aquifers. In 1930, there were 42 shallow wells. In 1939, there were 53 wells, partly in deeper aquifers. The shallow wells were closed in the period 1950 – 1960 and in the early 1990s La Cabine has 18 deeper groundwater wells.

Around the year 2000, research showed the vulnerability of the catchment area of La Cabine, caused by the infiltration of pollutants running off the nearby road. The province of

Gelderland and the water company (Vitens by then) decided to invest in a catchment reservoir for the runoff water. In the same period, it was considered to reduce the extraction at a Cabine to protect the nature reserve of the Veluwe and to expand the Sijmons facility instead. However, the excessive extraction of groundwater in the south of Arnhem can lead to shortage of water as well, especially in times of lower water levels of the river Rhine. Therefore, all water partners of Arnhem searched together for an integral optimization of the water cycle.

The high reservoir of Hommelseweg was expanded from 1500 to 3000, and around the 1950s to 5000 $m^3$, because the city of Arnhem grew.

#### 5.2.6 Softening at Sijmons?

Sijmons receives its groundwater both from the Veluwe area and the River area. The latter one is the area containing the cities situated below the river Rhine and above the river Waal. Therefore, its water quality differs from the water quality of La Cabine. The Sijmons treatment comprises aeration and rapid sand filtration. Initially, four filters were constructed, and around the 1990s the facility was expanded to a total of ten filters. The filtration capacity was expanded to reduce the filtration velocity and consequently reduce customer complaints on brown water occurrences.

The hardness of the water is depending on the amount extracted. Due to the hardness of the water softening was considered at various moments. Nuon, the then owner of Sijmons, commissioned Kiwa in 2000 to research the need and advantageous for softening at Sijmons. The investment in softening has not gotten priority so far (consideration of costs versus importance).

#### 5.2.7 Distribution network and pressure

Both production facilities supply water to an open network of the city, although the city is divided in several pressure zones, in order to meet the pressure targets, to limit the amount of energy and to prevent failure of the network system. Recently, the network of Arnhem is separated by closing the sag pipes. The south part of the city is served in a different way after reconsideration of the water supply plan after the merger (paragraph 4.3).

In some parts of the city, the pressure is rather high (6 bars) because of the historical development. Therefore, in the 1970s some the apartment buildings were not equipped with a water pressure installation. This might possibly lead to some discussion in case the water company plans to reduce the pressure further below four bars in the future.

#### 5.2.8 Organization water supply Arnhem

In 1991, the municipality of Arnhem (GEWAB) and the municipality of Renkum (GAWAR) merged to the provincial energy company N.V. PGEM. In 1994, the private enterprise Nuon acquired the facilities of PGEM. In the year 2002, the drinking water supply of Arnhem was transferred to Vitens, which was established through the merger of N.V. Waterbedrijf Gelderland, Waterleiding Maatschappij Overijssel and Nuon Water.

### 5.3 Nijmegen

#### 5.3.1 The first facilities

The council of Nijmegen established the municipal centralized drinking water company in 1879. The production facility The Nieuwe Marktstraat was situated close to their customers, in the city center at the south side of the river Waal. Initially, this facility had one groundwater well. The water was stored in the high reservoir of Kwakkenberg, south east of the city. A water tower was not necessary because of the height of the reservoir. The groundwater runs from the hilly south east side of the city towards the river Waal, north of the city center. The capacity of the treatment facility was expanded in 1909 and in 1920 to supply the growing water demand. Until 1985, the groundwater was distributed without any treatment.

### 5.3.2 The second treatment facility

In the 1940s, Nijmegen got its second production facility. This facility named Heumensoord (10 $Mm^3$/y) was required to meet the growing water consumption. It was situated in the woods, outside the city, in the south east of the city. Its water is soft and aggressive towards calcium carbonate, requiring conditioning prior to distribution. The marble filtration was installed around the mid-1990s after the Nijmegen assets got acquired by Nuon. The facility has over 40 groundwater wells.

### 5.3.3 Shut-down industrial extraction influences water quality

Two paper factories were located quite close to the Nieuwe Markstraat, since 1898 and 1908, and extracted large amounts of groundwater. In the 1970s, both paper plant sites were shut down, which was relevant for the extraction of the Nieuwe Marktstraat. Because of this shut down, the part of bank infiltrated river water in the extracted water at Nieuwe Markstraat increased. This probably led to the increase of the ammonium concentration in the source water, and therefore influenced the considerations for expanding the facility with water treatment.

### 5.3.4 Plans for adaptation of treatment Nieuwe Marktstraat

For a long time, the drinking water of the Nieuwe Marktstraat did not meet the future ammonia, iron and manganese standards of the 1984 drinking water decree. In the 1960s, it was considered to apply rapid sand filtration for removal of these substances. But in this period it also became desirable to adjust the water quality of both Nieuwe Marktstraat and Heumensoord in such way that customers would not experience any water quality differences anymore. The higher value of total hardness was one of the issues of Nieuwe Marktstraat with respect to these differences. The possibilities for hardness reduction were investigated in 1976.

Besides, in this period it was found that the groundwater of the Nieuwe Markstraat was polluted with solvents (volatile organic compounds such as tri) which were used for degreasing in the metal industry. The original polluted soil was restored, but the solution stayed present in the deeper soils. In the early 1980s, research tests were performed at the facility with air stripping for removal of these volatile compounds.

### 5.3.5 Renovation of treatment Nieuwe Marktstraat

In 1985, the facility was thoroughly renovated. The treatment comprised air stripping (removal of volatile compounds), softening and rapid filtration (removal of iron, manganese and ammonium). The design had accounted for the eventual revamp of the treatment with activated carbon filtration, anticipating on the development of the groundwater quality. The air stripping installation was designed to reach a final concentration below 0,1 μg/L for the volatile compounds, because it was believed that this would become the new standard of the revised water decree. The standard turned out to be 1 μg/L, hence the installation was overdesigned.

In 1988 the herbicide bentazone was found in the urban groundwater. As a solution, the capacity of the facility was reduced initially, although this would lead to the shifting of the herbicide to other wells. This reduced production needed to be compensated by additional production at Heumensoord. However, this facility had reached the maximum permitted extraction. Because of this fact and because of the reduced redundancy of the system, it was required to fully restore the production capacity of Nieuwe Marktstraat.

In the late 1990s, it was considered to enhance the softening of the water. Reasons to do so were complaints about the high lime precipitation potential of the water, and the future possibility given by the revised drinking water decree of 2001, to soften water below 1,5 mmol/L. The softening was not enhanced, since it would not further reduce the lime precipitation potential in this case. Instead, the water quality was improved by controlling the acidity.

### 5.3.6 Activated carbon filtration

The Nieuwe Marktstraat facility was expanded with the installation of activated carbon in the early 1990s. In the beginning of the 21st century, it was decided to adapt the facility of Nieuwe Marktstraat from treatment plant and drinking water distribution station to a groundwater extracting satellite with partial activated carbon treatment only. The groundwater was transported to the facility of Heumensoord and mixed with the Heumensoord drinking water. In such way, the higher nitrate concentrations of Heumensoord and the higher hardness levels of Nieuwe Marktstraat are reduced at the same time.

Due to this adaptation, the treatment plant of Nieuwe Marktweg was taken out of operation, and a transport pipeline was constructed to transport the raw water to the Heumensoord facility in the south east of the city. In the near future, the groundwater extraction at Nieuwe Marktweg will be stopped as well, and the city will be served with water in a different way because of a renewed water supply plan (paragraph 4.3).

The facility of Heumensoord was renovated in the 1990s. One of the reasons for renovation was to adjust the facility to the newest automation standards. The increased automation led to the saving of drinking water and energy.

### 5.3.7 Organization water supply Nijmegen

In 1989, the Zuid-Gelderse Nutsbedrijven (ZNG) is established, after the merger of the municipal activities of the city of Nijmegen (Openbare Nutsvoorziening Nijmegen) en the gas company of the south east part of the province of Gelderland. Nuon acquired ZNG in 1994. In the year 2002, the drinking water supply of Nijmegen was transferred to Vitens, which was established through the merger of N.V. Waterbedrijf Gelderland, Waterleiding Maatschappij Overijssel and Nuon.

### 5.3.8 Development of the city and distribution in Nijmegen

The city of Nijmegen expanded on the north side of the river Waal relatively late in comparison to Arnhem. One of the planned expansions is the district of Waalsprong, at the north side of the Waal. This area was only developed in the late 1990s, and the annexation of the town of Lent was required. When the city grew due to annexation, the drinking water concession north of the river Waal still belonged to N.V. Waterbedrijf Gelderland, and the city of Nijmegen was supplied with water by Nuon.

The investment for new households connections were cut back because the development of the Waalsprong district near Nijmegen initially was postponed. Around 2001, the pipeline connection to the Waalsprong district was designed at halve of the required water consumption, because this district was planned to provide its own water for household purposes (grey water). At that time, Nuon was active on the grey water market. The development of the grey water market were forced to stop by the government after cross connections between the drinking water and the household piping systems led to incidents concerning public health at a project in Leidsche Rijn. Due to the absence of grey water in the Waalsprong district, a new transport pipeline was required to make up for the shortage of water that might occur when the district will grow further.

Nijmegen has several pressure zones. The largest zone is the middle pressure zone. There is a small zone around high reservoir Kwakkenberg. After the facility of Heumensoord was constructed, a low pressure zone was created. The Nieuwe Marktstraat will be closed in the near future, which is compensated by the supplying from Fikkersdries, approximately 10 km north west from the city. This change of water distribution will involve a reduction of a part of the pressure of the current middle zone.

## 5.4 The cities of Arnhem and Nijmegen and the River-area in the 21st century

Prior to several mergers of water companies of the province of Gelderland, the larger cities in this province, such as Nijmegen and Arnhem, could more or less be considered as autonomic, isolated areas. The cities hardly had any pipeline connections to the provincial areas. Because of the merging of water companies, these isolated areas became part of a bigger infrastructure on a provincial (exceeding) scale. Hereafter, some of the large infrastructural developments in the River-area and the Achterhoek region are described. The Achterhoek region is situated east from Arnhem and Nijmegen. These developments have mostly occurred in the last decade, or are still planned to happen in the near future.

### 5.4.1 Mid-1990s situation

In the mid-1990s, the River-area, including the cities of Arnhem and Nijmegen and the provincial area between the Rhine and Waal rivers, was served by N.V. Waterbedrijf Gelderland (70%) and Nuon (30%). Roughly speaking, the cities (Arnhem and Nijmegen) were served by Nuon and the provincial area was served by Waterbedrijf Gelderland. Groundwater is abundant in the River-area, and it contains several groundwater facilities, for instance Fikkersdries.

In 1994, the then five water companies of the province of Gelderland agreed with the Province that the backwash water would be treated and that the sludge would be reused. In this way the backwash water would not infiltrated and the soil would not be polluted with byproducts of drinking water production. Approximately ten years later, these backwash water treatment facilities were realized.

### 5.4.2 Ten-year planning provincial water company

The Waterbedrijf Gelderland made a ten-year investment planning in 2002, accounting for water quality improvement, capacity expansion and renovation requirements. They planned to switch from small scale production facilities in the Achterhoek region to large scale production facilities outside this region. Reason for shutting down the small scale facilities in the Achterhoek is the incentive to supply softer water, the drive for clustering towards larger scale facilities (also, because treatment might get more complex because of softening) and to reduce the dry out of soil in the Achterhoek region. In this plan, large transport pipelines are required to supply the Achterhoek region with drinking water. Two options were considered: i) production at the Overbetuwe facility (to be built) or ii) purchase drinking water from Germany.

The adaptations planned in 2002 for the Gelderland region can be summarized:

- Reduce dry out of soil in vulnerable regions (Achterhoek, Veluwe). For the Veluwe area, the Province of Gelderland targets at a reduction of groundwater extraction of 25% compared to 1994.
- Realization of additional treatment in order to improve of water quality, preferably on larger scale facilities (clustering). This requires larger scale transport of water from neighbor regions.
- Connection of several production facilities in order to ensure a reliable supply.

The groundwater of the Ede facility, north-west from Arnhem, is of excellent quality and does not need any treatment. Therefore, its water is rather cheap. However, the extraction permit of this facility needed to be reduced due to the sparing of natural reserve of the Veluwe. This was compensated with the construction of a transport pipeline from La Cabine to the area of concern. In the meantime, most of the groundwater extraction permits imposing risks for dry out of soil still exist, but compensating measures have been taken by infiltrating water or replacement of the extraction to deeper aquifers.

### 5.4.3 Merger of provincial water companies and Nuon to Vitens

In the beginning of the 21st century, the cooperation between Waterbedrijf Gelderland, Waterleiding Maatschappij Overijssel and Nuon was intended. The abovementioned investment planning of Waterbedrijf Gelderland was based on the Long Term Plan Drinking water that was prepared in cooperation with Waterbedrijf Gelderland and Waterleiding Maatschappij Overijssel, and it was adjusted to the investment plans of the latter one.

Vitens was established through the merger of Waterbedrijf Gelderland, Waterleiding Maatschappij Overijssel and Nuon in the year 2002. In 2006, Nuon retreated from the drinking water market and sold its shares to Vitens. In 2006, Vitens expanded further through additional mergers. Some of the abovementioned investment plans of the provincial water companies were adapted after the merger of the water companies:

The Fikkersdries facility in Driel was expanded from 12 to 24 Mm3/y by connecting the catchment area of Overbetuwe (Hemmen and Zetten) to Fikkersdries, rather than investing in a new large production plant at Overbetuwe. Fikkerdries has excellent groundwater quality, and its treatment comprised aeration and rapid sand filtration. The Fikkersdries I facility was expanded by the construction of a new, separate facility Fikkersdries II. The reason for this change was economy of scale, which had been introduced successfully in other regions within Vitens. The facility of Lent was closed because of water quality issues, after Fikkersdries was expanded.

The construction of the Overbetuwe facility was planned in the 1980s – 1990s in order to be prepared on the expected increase of the water demand. The permit for extraction at Overbetuwe was obtained in 2001, under the conditions that the extraction at two different sites would be left (Lent) of reduced (Druten) In later plans, the facility of Overbetuwe was also considered to replace small scale facilities in the Achterhoek region which produced drinking water with high hardness levels. Hence, previously a new facility at Overbetuwe was planned to anticipate on the expected demand increase and to replace smaller facilities. After all, no facility is constructed at Overbuwe, and its water is transported to be treated at Fikkerdries.

Plans were to supply the Achterhoek region with Fikkersdries. However, in 2014 Fikkersdries is serving the Arnhem south area and a part of the city of Nijmegen, next to its local area.

Instead, the Achterhoek region is served by the facility of Sijmons (south of Arnhem) and a few larger centralized softening plants in the Achterhoek region.

The shut-down of the smaller facilities in the Achterhoek region and its compensation with water from the west required the investment in large transport pipeline works and centralized softening plants. Also, the city of Arnhem needed to be separated in two zones. This change led to a decrease of the pressure in the south part of the city.

The option for purchasing water from Germany was not further developed, since the company wanted to be independent.

#### 5.4.4 Some recent plans affecting Arnhem and Nijmegen

Vitens and the Province of Gelderland agreed in 2008 to reduce the amount of groundwater extraction permits. The great number of permits is caused by the expectations for an increasing demand in the 1970s and 1980s in combination with the original existence of a great number of separate drinking water companies in this region. The number of permits were agreed to be reduced because a permit for groundwater extraction hinders the possible development for alternative activities. Several permits were returned to the province, and as a consequence some production facilities were shut down. In 2010, Vitens developed an updated plan for a ten year period. In this plan, it is recommended to optimize the capacity of Fikkedries versus the capacity of the west of the River-area.

Because the Nieuwe Marktstraat facility in Nijmegen is shut down, a new large transport pipeline is planned from Fikkersdries to the city, crossing the river Waal.

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## 5.6 Interviews

November 2013 – January 2014

- Gijs Giesbers
- Guus van de Kraats
- Paul Boeijen, via Ger Giesbers
- Hennie te Dorsthorst

# 6 Maastricht

## 6.1 Summary infrastructural development Maastricht

The basic outline of the drinking water infrastructure is rather constant during the entire period. Groundwater has always been used as drinking water source. The required treatment of the groundwater has always been limited, although disinfection was required in some cases and the treatment is expanded with softening. The building of a nitrate removal plant could be prevented by cooperating with farmers, as well as mixing with water with low nitrate levels. The city got served by two or three groundwater facilities until the 21st century. Some facilities were closed, because of water quality or capacity problems, only after they could be replaced by new facilities. In the beginning of the 21st century, the switch from separate drinking water production facilities to centralized softening was realized. This project, together with the acquisition of the municipality of Maastricht by the provincial water company WML (around 2000), had great impact on the main distribution infrastructure since water supply plans were considered in an integral way on a larger scale. The availability of groundwater has always been really scarce on the west side of the river, and groundwater was abundant east of the city. Many efforts were done to find adequate groundwater sources on the west side of the river, which was hardly successful because of water capacity and quality problems. This also explains the existence of several transport pipeline connections crossing the river, and the presence of high storage reservoirs at the west side of the city.

An overview of the urban area of Maastricht and some drinking water production facilities is presented in Figure 10, according to the situation in 2014 (except Borgharen and Caberg which have been shut down).

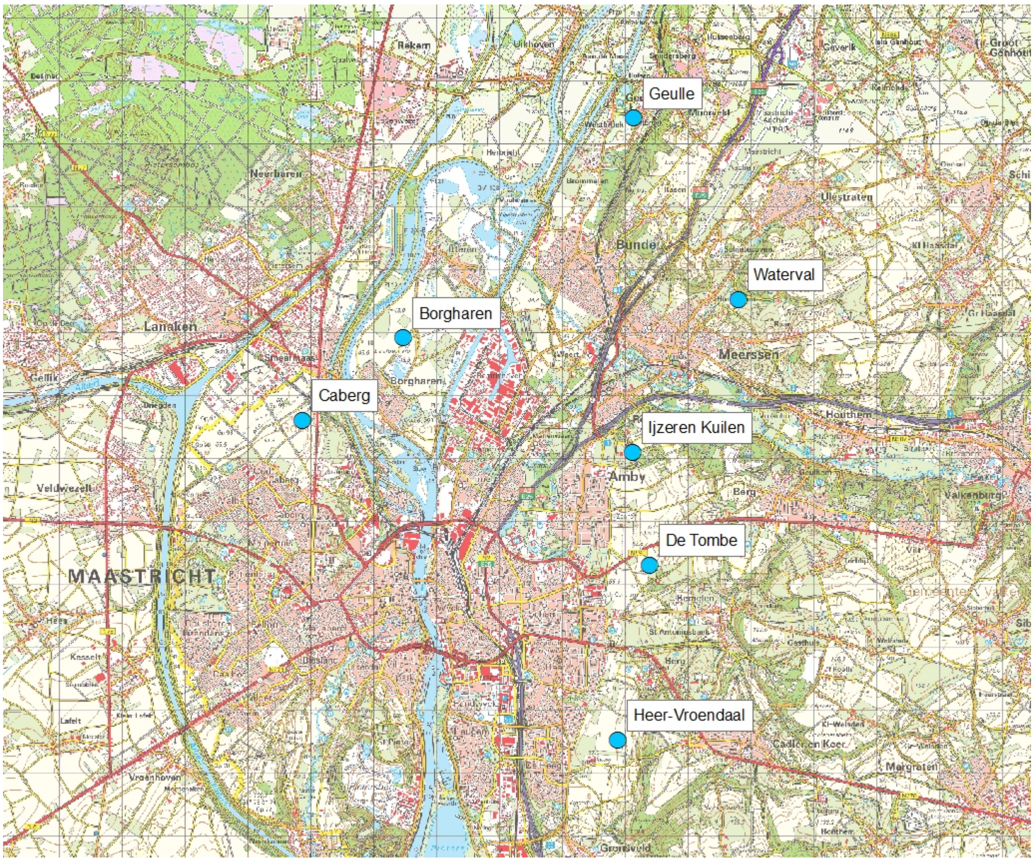


FIGURE 10; OVERVIEW OF URBAN AREA AND PRODUCTION FACILITIES OF MAASTRICHT IN 2014 (BORGHAREN AND CABERG ARE CLOSED).

## 6.2 The initial facilities

The first plans for the establishing of a drinking water company in the city of Maastricht originate from 1880. The drinking water company 'Waterleiding Maastricht' was established in 1887 and was exploited by the private enterprise 'Waterleiding Exploitatie Maatschappij' of Rotterdam. In the preceding decennia, the city was confronted with a great number of devastating fires. The drinking water company was established because of public health reasons and in order to increase welfare, but immediately proved to be of great help to firefighting as well. It lasted for quite some decennia before the concession was sold to the city council and the water company turned into a municipality. Similar developments occurred with respect to public transport en energy supply (both gas and electricity) in this period.

The city of Maastricht was supplied with water by the Heugemerweg facility (250 $m^3/h$), which was situated at the east side of the river Meuse. Heugemerweg distributed untreated groundwater. The connection between the east and west side of the river was assured through the construction of a sag pipeline in 1886, which was used until 1959. A second connection was constructed via a transport pipeline in the Sint-Servaas bridge.

The Heugemerweg production facility was located just outside the city of Maastricht. The groundwater quality was quite good despite the close location to the river. The council of Maastricht could not prevent the building of houses and manure pits in the village of Heer, which was located upstream from the extraction and consequently threatened the drinking water quality. The city council only was willing to acquire the drinking water company under the condition that a new facility could be developed. In 1916, water abstraction tests were performed near the village of Amby, also east of the city and outside the city borders.

## 6.3 Concession acquired by city council and further development of facilities

In 1918, Maastricht acquired the concession and opened the public water works. The Amby facility was not further developed yet, although the site first had been acquired. In 1921 the temporary back-up facility Kastanjelaan was built at the west side of the river. This additional facility was required because of the increase of the water usage per person and the growth of the city, and the fact that water pressure was too low to supply water on the first floor of houses in the West part of the city. In this period, shortage of water was quite common. After the well water got infected in 1926, its water needed chlorination because of public health, which was unfavorable to the waters taste. Also, the production was limited in an attempt to manage the problem.

Besides the building of this additional facility at Kastanjelaan, the water usage was attempted to control by avoiding leakage and frequent repair of broken mains, discouraging misusage, changing of the tariff structure and introducing water metering. In 1920, the Heugemerweg facility broke down because of flooding by the river Meuse. The city was left without water for quite some time. The water supply was partly rebuilt with help from firefighting department of Amsterdam and The Hague. The drinking water was not safe and had to be chlorinated. The increased customer complaints finally led to the building of the new facility Amby in 1925. The Heugemerweg facility was sold to a pottery company (Société Céramique) for industrial water purposes in 1926, after it was no longer used for drinking water purposes.

The facility of Amby was located on the east side of the river, and was connected with the west side through a sag pipe. The city only had one high reservoir, situated at the hill of St. Pieter at the west side, which was built in 1886 with a volume of 800 $m^3$. The back-up facility Kastanjelaan was connected to the reservoir as well. A second high reservoir was built in 1932 with a capacity of 2000 $m^3$. With this new storage facility, the water supply got more reliable and energy costs dropped because of production outside peak hours.

## 6.4 Mineral water

The shallow wells of Kastanjelaan were planned to be abandoned in 1927, and the presence of drinking water in deeper aquifers was investigated. At great depths of 300 m, no potable water was found. However, a salty, warm mineral water source was discovered, which was marketed as mineral water (Tregawater). Since this deeper connate water was of no use for the public water works, the Kastanjelaan was revised in the 1930s. In the period 1945 – 1960, several attempts were done to fix the bore pipe of the Tregasource which was damaged by corrosion. Amongst one of them, an attempt was made by the Dutch oil company (NAM). These defects caused the contamination of the nearby water of the Kastanjelaan, leading to an increasing chloride concentration. Its chloride concentration rose beyond tolerable levels (250 – 450 mg/L). The deep mineral Trega source was closed in 1960 because of sintering of the well, water pollution and material corrosion. Also the Kastanjelaan facility was closed down in 1960.

## 6.5 The 1930s

In the 1930s, an alternative site near the village of Caberg, north-west of the city, was purchased and first abstraction tests were performed. In 1932, the city council of Maastricht sold the water supply concession for the villages of Amby (the Amby *facility* of the city of Maastricht was named after the *village* of Amby) and Heer to the water company 'Waterleiding Maatschappij voor Zuid-Limburg' which was established in 1925. The latter water company started the facilities of Heer in 1936 and IJzeren Kuilen in 1943, at the east side of the river. Both facilities distributed it's the extracted groundwater without treatment. One of the reasons to start the extraction in Heer was the inconvenience caused by the high groundwater level which occurred at higher river water levels. Similar phenomena hold for other facilities nearby (Amby, IJzeren Kuilen): people might experience inconvenience of rising ground water levels in case the water extraction would stop. Both facilities Heer and IJzeren Kuilen are still operational in 2014.

Contrary to the public gas company, the public waterworks were facing an increase in the water usage. After the war, the production and transport works had almost reached the capacity limits. Plans for the infrastructural development were made in cooperation with the National Institute for Drinking water supply (RID). In the meantime, measures were taken to inhibit the waste of drinking water. Also, an agreement with a porcelain manufacturer (Sphinx) was made to support the public waterworks in times of shortage. Both facilities Amby and Kastanjelaan produced at their maximum capacity, when the third water well was constructed at Amby in 1945. In 1947, the temporary transport pipeline connecting the city parts via the Wilhelmina bridge got frozen because of extreme winter conditions. The pipeline got equipped with flushing facilities in order to force flow and prevent future freezing.

## 6.6 Novel pump technology

Until 1950, groundwater abstraction was performed with suction pumps. These pumps were placed above the water level in order to remain dry. The constructed wells had to be broad because of the size of the pump. The construction of such shanks (2 m wide, 10 – 20 m deep) was time consuming and expensive, and these efforts limited the depth and therefore the capacity of the well. In 1948, the submersible pump was developed. Due to this development, water from greater depths and deeper aquifers became available. In many places, phreatic and artesian water was becoming less abundant. The soil in the region near Maastricht consists of limestone. The limestone is characterized by the presence of cracks, which cause the groundwater level to drop significantly when large amounts of water are subtracted. The introduction of the submersible pump resulted in an increased accessibility of groundwater. They were successfully applied in 1950 at Amby, and later at different facilities in this region as well. The investment in two new deep wells was required at Amby, because the drinking water company 'Waterleiding Maatschappij voor Zuid-Limburg' started abstracting on a new site close by, at the site of IJzeren Kuilen which was started in 1943.

## 6.7 1950s

In 1949, a second transport pipeline was constructed from Amby, and connected to the pipeline at the Wilhelmina bridge. In spite the increased supply reliability with this additional transport pipeline, the search for a new facility at the west side of the river continued. The Caberg site was tested again in 1950, and this time the attained capacity was promising. However, the raw water at this site was not suitable for direct distribution without treatment. In 1953, the new facility of Caberg was built, comprising aeration, filtration and storage, with a limited production capacity of 200 $m^3$/h. The extraction capacity was limited because of the aquifer properties. A new transport pipeline was built in order to connect the new facility to the existing mains. The Caberg facility supplied the water for the higher parts of the city. After the construction of Caberg, the drinking water facility at Kastanjelaan was closed because of insufficient water quality (chloride, microbiological contamination) and the capacity available at the west side of the river because of the Caberg facility. The third storage reservoir was built in 1952 at the higher west part of the city (St. Pieter), with a capacity of 1000 $m^3$, with which the water pressure was increased in the higher parts. The connection coverage of households increased from 75% in 1947 to 95% in 1958, also because of the 1950 regulation which stated the connecting of households close to the water mains.

## 6.8 Shut-down Amby and start-up De Tombe

The Amby facility was closed in 1976 because of water quality issues (mostly nitrate) and because the city needed to expand in this area. This facility was replaced by De Tombe facility, which is currently still operational. De Tombe is located east from the villages Heer and Amby, which were served by the water company of the province of Limburg (WML). Hence, the transport pipelines from De Tombe towards the city of Maastricht crossed the WML service area. The groundwater of De Tombe was distributed without treatment, but because of bacteriological contamination the water had to be treated with UV-disinfection in the late 1980s. The UV apparatus was removed recently because of an improvement of the raw water quality.

## 6.9 Alternative sources

The city council investigated several possibilities for groundwater extraction suitable for drinking water purposes, probably in order to guarantee the drinking water supply without getting dependent of the provincial water company WML. From tests in 1941 near Eijsden it was concluded that the groundwater was brackish (high chloride concentration) only at a depth of 50 m. Salt water fishes were kept in a nearby pond. In spite of the presence of limestone, upconing of brackish water may occur upon groundwater extraction due to the geological characteristics of the soil (Carboon). In 1964, two more different sites (Jekerdal and Oost Maarland) were tested for the presence of adequate groundwater. The sites did not turn out to be suitable for drinking water production because of low capacities and water quality issues (nitrate, pesticides, contamination by surface water, higher salt concentrations).

## 6.10 Search for water on the west side

Throughout the history of the drinking water supply, the municipality of Maastricht has been searching for an adequate ground water source on the west side of the river. On the east side, groundwater extraction is easily possible because of the soil properties. The capacity of the aquifer is sufficient because the underground on the east side consists of gravel above limestone. However, the permit of the municipality of Maastricht was limited because WML also obtained groundwater extraction permits in this area. On the west side, the aquifer mainly consists of limestone. In the lower parts of the west side, limited extraction was possible, but the water was often of poor quality. In the higher parts on the west side, the availability is limited because of underground properties, water quality issues and high investment costs necessary to construct wells deep enough for water extraction (prior to the invention of the submersible pump). On the west side, extraction in the valley of the Jeker river was investigated, but water quality was poor (nitrate, pesticides). Besides, the availability was limited due to the extraction of the quarry of the cement company ENCI. The ENCI started limestone extraction in 1926, and reached the groundwater level in the 1980s – 1990s. The groundwater was extracted to maintain the quarry dry. It was considered to reuse the water for drinking water purposes, but because of the poor water quality and high costs for water transportation – given the fact that the quarry was planned to be closed down soon – these plans were not further developed.

In the early 1970s, the water company WML started tests at The Dommel site. This site is quite close to the abovementioned sites, but its location is higher and the limestone conditions are more favorable. The facility of The Dommel was built by WML in 1975. The groundwater had low chloride concentration, however the nitrate concentration was high and sometimes the water was microbiologically unsafe. However, the water quality standards were met and the groundwater of The Dommel was distributed without treatment.

## 6.11 1970s: new extractions lead to capacity problems

In the late1970s, De Tombe facility of the municipality of Maastricht got severe capacity problems, because of the close-by groundwater extraction of the IJzeren Kuilen facility of WML. Some wells could not provide sufficient water anymore. The municipality and WML had disagreements about the issue, leading to court trials. Because of these capacity problems, the Borgharen facility (named after the village of Borgharen) was started by the city of Maastricht in 1978, after having plans for its development for quite some time. The facility treated groundwater with aeration and filtration, and was connected to the city through transport pipelines. The Itteren site, close to Borgharen, was allocated by the province for optional drinking water application for the city of Maastricht. The site was never developed, and in the 1980s, the groundwater protection allocation was cancelled. The villages of Borgharen and Itteren were served by WML.

Both Borgharen and Itteren would lose the groundwater protection status in case the close by upstream area would be developed for industrial purposes. Indeed, later the area was developed for industrial activities with a great number of companies and an inland port.

## 6.12 Acquisition of municipality by WML

It was stated by law that water companies had to strive for organization on a larger scale (e.g. provincial) by merger. The Waterleiding Maatschappij voor Zuid Limburg (the south of Limburg) had grown to the drinking water company of the province of Limburg WML (Waterleiding Maatschappij Limburg). Maastricht was one of the last Dutch municipalities that merged with the larger drinking water company. Early during the 21$^{st}$ century, WML overtook the operations of the facilities. The legal acquisition occurred a few years later. At that time, the city of Maastricht had three production facilities: Caberg, Borgharen and De Tombe.

Next to the facilities of Heer and IJzeren Kuilen (mentioned above), WML had the facilities Geulle (1932 – present) and Waterval (1961 – present) near the city of Maastricht. The groundwater of Waterval needs treatment with aeration and filtration, whereas the groundwater of the Geulle facility is untreated.

## 6.13 Softening

In the 1990s, both the municipality of Maastricht as well as WML developed several strategies for central softening. The groundwater has the highest levels of total hardness in The Netherlands because of the properties of the limestone soil in this area. Hence, the most important reason for softening was customer satisfaction. Both companies carried out various studies, in which the availability of groundwater, the treatment scale and the location of softening plant formed important variables. The WML plans aimed for centralized treatment of the groundwater of IJzeren Kuilen, Waterval, Geulle, The Dommel and Heer. Maastricht studied several plans, such as decentralized or centralized softening of the three facilities, cooperating with WML, and purchase water from Belgium. Parallel, the negotiations between Maastricht and WML on the acquisition of the Maastricht assets by WML intensified.

In 2001 it was decided to build one softening plant at the site of IJzeren Kuilen, east from the city, at which the water of Geulle, Waterval, Heer, De Tombe and IJzeren Kuilen is centrally treated. De Tombe (Maastricht) was planned to be connected to the softening plant anyway, because of its location between the facility of Heer (WML) and the softening plant. The facility of The Dommel was not connected and shut down, because the costs of connection to the softening plant would be too high, the water quality was poorer (high nitrate concentrations, and bacteriologically less reliable), and due to the abundance of water. With the start-up of the softening plant, initially the villages east of Maastricht received softened water, secondly the east part of the city (2005) and finally the west part of the city as well (2008). This phasing was caused by large transport pipeline works that were required to the central plant and back to the city.

Together with the final transport pipeline constructions in 2008, the facilities of Caberg and Borgharen were closed. These facilities were shut down because of several reasons: i) water got abundant due to the investment in a large transport pipeline between the area of Maastricht and the middle part of the province, ii) the Caberg and Borgharen water had high hardness levels, iii) water quality was threatened because of risk of flooding of the river Meuse and industrial activities (inland Beatrix port, Juliana canal, garbage dump), iv) the connection of these facilities to the central softening plant would have been expensive because of crossing the river Meuse, the Juliana canal and the A2 highway. The investment in an additional transport pipeline from the softening plant back to Caberg was optional, but the three existing river crossing connections turned out to be sufficient, also because of stagnation of the water demand.

## 6.14 Treatment

During the period between 1887 and the present, a significant part of the water was distributed without treatment. The water of the first facilities of the city (Heugemerweg and Kastanjelaan) needed chlorination from time to time. Some of the water needs aeration and filtration, and a small part of the water was treated with UV-disinfection. Since the beginning of the 21$^{st}$ century, the water was centrally softened. A significant part of the groundwater near Maastricht contains high nitrate levels due to the fertilizer applied in agriculture in great excess for many decades. The nitrate drinking water standard was lowered from 100 to 50 mg/L. On the other hand, the regulation of fertilizer usage got more stringent. The development of the nitrate concentration is closely monitored by WML. Since 1998, WML investments are aiming for sustainable groundwater quality in cooperation with farmers, in order to prevent investing in a nitrate removal plant. These investments comprise the stimulation and advising of farmers regarding cultivation of crops, and compensation measures regarding specific costs made by farmers. So far, this policy has proved to be successful since the excess of applied fertilizer is reduced and the construction of a nitrate removal plant still can be prevented.

## 6.15 Storage and distribution

The transport pipeline structure of the municipality of Maastricht and WML (and its predecessors) never had connections of great importance. Only a couple of small connections existed to provide some support during calamity situations. These small connections are removed because a reliable supply is guaranteed by more recent transport pipeline connections which integrally cover the supply of the city and its surroundings.

In 1960, the city had three reservoirs. Two high reservoirs are left in 2014. The highest reservoir at the hill of St. Pieter was removed because of digging activities in the nearby quarry of the cement company ENCI. The storage of Louwberg was recently expanded because of reliability of supply, and the St. Pieter reservoir was renovated. Also, the booster pumps at Zakstraat and St. Pieter have been there for decades and are renovated. Besides these reservoirs, the city used to have a water tower near the Heugemerweg facility. In the same period of the construction of the softening plant, WML invested in demand forecasting software. With this software, it became necessary to utilize the entire storage volume of reservoirs rather than striving for the reservoir to be completely filled all the time. With this software investment, the water production could be flattened during the entire day. Also, in this period storage and pump capacities were designed more accurately, hence at lower redundancy levels. It took a while for the operators to get used to this new operational modus, mainly because the reservoir level was planned to decrease significantly during the day.

## 6.16 River crossings

The first river crossing transport pipelines were built in the nineteenth century. In the twentieth century, the city built several more bridges because of increased traffic intensity. In World War II, two bridges got damaged. The temporary Wilhelmina bridge got equipped with a pipeline on the outside, which would freeze during harsh winters. In 1958, the transport pipeline was connected to the renewed Wilhelmina bridge. In 1960, a new sag pipeline was constructed, closely located to the Kennedy bridge (built in 1968). In the north of the city, a second sag pipeline was constructed in 1969. In 2014, the city has three river crossing connections in order to provide a reliable water supply.

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## 6.18 Interviews

October – December 2013:

- Maria Juhász-Holterman
- Anton van Eijden
- Laurent Schrijnemaekers, via Maria Juhász-Holterman

# 7 Amsterdam

### 7.1 Summary infrastructural development Amsterdam

The city of Amsterdam is supplied with drinking water which is produced at two different sites, namely Leiduin and Weesperkarspel. Both surface water facilities were built in the nineteenth century. The Leiduin site was built in 1853 and was initially operated by a private enterprise, the Dune Water Company (Duinwater Maatschappij). In 1896, the concession of the Dune Water Company was sold to the municipality of Amsterdam. For about a century, the Leiduin facility extracted water from the dunes when it was shown that the dunes got depleted and upconing of brackish water occurred. In order to replenish the dunes with freshwater, a large scale pretreatment of river water and extended distance transport works were realized mid-20$^{th}$ century. The Weesperkarspel site was built in 1888, but for many decades the water was not suitable for drinking purposes, because of the poor quality of the source. After several source switches, the river water source was replaced by lake water in the 1930s. Its water quality improved significantly, and therefore the double distribution network, which had separated the potable water of Leiduin and the non-potable water of Weesperkarspel for many decades, could be eliminated. In the past decades, both the treatment of Leiduin and Weesperkarspel have had many capacity expansions and process adaptations, in order to meet growing water demands and anticipate on changes of the source water quality and meeting more stringent quality demands. Also the transport pipeline infrastructure, both of source water and drinking water, and the storage capacity works were expanded many times to meet growing water demands and to increase security of supply. Since 2006, the municipal water company of Amsterdam is named Waternet, and is the first and only water cycle company of the Netherlands.

Besides Leiduin and Weesperkarspel, Amsterdam had a small groundwater facility (3 – 5 $Mm^3/y$), which was built 1890 and shut down in 1988 because the water got polluted with volatile organic compounds. Developments regarding this facility are not included in this description. Hereafter, the historical development of both the Leiduin and Weesperkarspel facilities are described. The major investments are mentioned as well as the drivers behind the investments. This Amsterdam case focuses on infrastructure related to the drinking water source and its treatment, although some transport, storage and distribution works are described as well.

Figure 11 presents an overview of the main infrastructure of Waternet (status 2014).

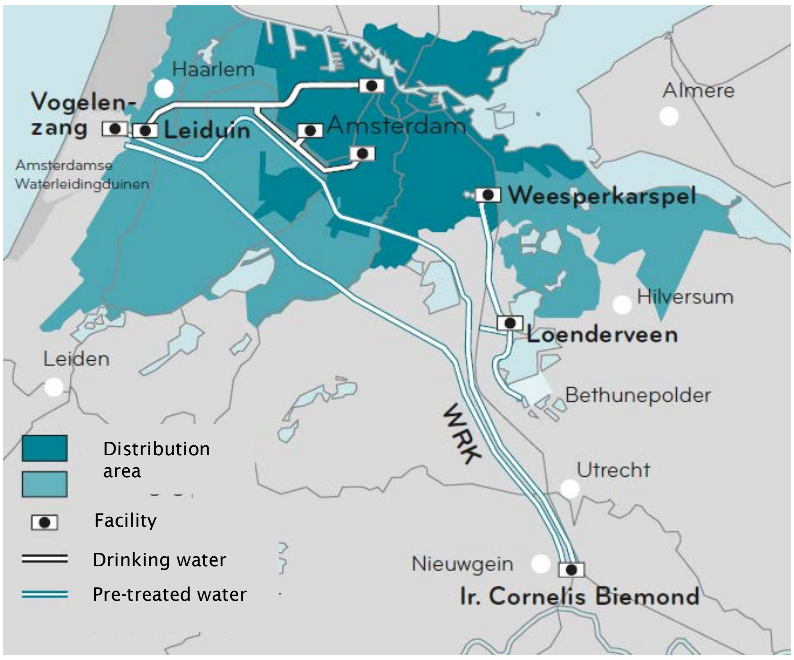


FIGURE 11; OVERVIEW MAIN INFRASTRUCTURE WATERNET (STATUS 2014).

## 7.2 Leiduin

This chapter describes the investments and developments of the Leiduin site, but in some cases the developments of the Weesperkarspel site are mentioned because of the interdependent relation between Leiduin and Weesperkarspel.

### 7.2.1 The first decades: Leiduin for drinking and Weesperkarspel for cleaning

The Leiduin site is situated in the dunes southwest of Haarlem, and it was first constructed in 1853. Shallow dunewater was abstracted through open channels functioning as drains. For about one century, the dunes were replenished by rainfall only; later the dunes would be infiltrated with surface water. The drinking water was transported to the city of Amsterdam through a 23 km long pipeline. Dune water was not always abundant because the aquifer got depleted, leading to low water pressures. Also, the transport pipeline got frozen in some winter times. After a few decades, it was decided to build the second treatment plant of Weesperkarspel, east from the city. In the first decades of its existence, the water of the Weesperkarspel plant was not suitable for drinking water purposes.

In combination with the ever growing amount of inhabitants, the Leiduin facility needed expansion. The permitted amount of deep dunewater extraction was exceeded as early as 1908. The water extraction was continuously larger than the water replenishment, causing the freshwater stock in the dunes to decrease slowly. As a consequence, upconing of deeper, brackish water took place.

In 1900, the production facility was renewed and expanded, with new slow sand filters and a pumping installation. The new pumping installation, distributing the water from Leiduin to the pumping facility at the Haarlemmerweg, lasted from 1900 till 1961.

Around 1900, the city center was served through pipelines of which a few were installed as sag pipes, in order to cross the city canals. Many more sag pipelines were constructed in the years after, amongst several sag pipes crossing the IJ water.

In 1920, the building of the pre-filtration and new slow sand filtration installations started. Prior to the filtration, the deeper subtracted dune water needed aeration because oxygen was absent and the water contained some iron. After subtraction and prior to treatment, the water was – and still is – collected in the reservoir 'Oranjekom'. The transport pipeline connecting the extraction area in the dunes to the Leiduin treatment facility needed frequent cleansing, because of biological fouling (algae and shell-fish). The pumping capacity at the Oranjekom facility was expanded in the 1930s in order to meet the increasing demand. Also, later in the 1920s the pre-filtration and slow sand filtration section was further expanded. The pre-filtration installation was replaced by rapid sand filtration in the mid-1950s.

New districts were annexed by the city of Amsterdam in the 1920s, and all of the districts were planned to be connected to the centralized drinking water system. In this period, low water pressure problems at upper levels of houses were solved with the installation of additional transport pipelines and an extra booster station. In 1916, the first transport pipeline was taken out of operation, and after, the water was transported to the city through three pipelines. In this period, the possibilities of new water sources were investigated for the Weesperkarspel site, due to the increasing water demand as well as the quality of the Weesperkarspel source.

### 7.2.2 The 1930s: continuous growth, plans for expansion and quality improvement of Weesperkarspel

In 1929, it was decided that the Weesperkarspel water needed to be made suitable for drinking water purposes as well. The city council considered the possibility to use a water source tens of kilometers land inward, near the river Lek, close to the city of Utrecht. Besides, they decided to investigate the possibilities of artificial infiltration of freshwater in the dunes, which was first proposed in the beginning of the twentieth century. Finally, in this period it was decided to expand the dune water collection facilities.

In 1934, the then director of the water company (Gemeentewaterleidingen) proposed a plan with two leads. This plan comprised of artificial infiltration of river water in the dunes and the expanding of the capacity of the Weesperkarspel plant.

In 1948, the fourth transport pipeline between Leiduin and the city was constructed, in order to manage a reliable water supply. Because the scarcity of iron, the pipeline was constructed of concrete. The different transport pipelines between Leiduin and the city have several cross connections, in order to improve the reliability of supply. The storage capacity at the Haarlemmerweg site was expanded again, in 1953. Also, the slow sand filters were covered in the 1950s, in order to prevent freezing of the water during winter time and prevent algae growth during summer time.

### 7.2.3 The 1950s: establishment of WRK and start of dune infiltration

In the early 1950s, an important decision was made by the council of Amsterdam and the Province of North-Holland. They established the N.V. WRK (Watertransportmaatschappij Rijn-Kennemerland), which would become responsible for the transport of river water from the Lek near the city of Utrecht to the dune area of Leiduin and to the province of North-Holland. The river water would be used to replenish the dune water aquifer. With this option, the existing infrastructure comprising abstraction, treatment, transport and distribution, could be maintained. In the province of North-Holland, the water demand (both domestic as well as industrial) was expected to increase as well.

The location of the WRK extraction facility at Jutphaas, near the river Lek and south of the city of Utrecht, was chosen after objections had been raised by the city of Utrecht on extraction north from the city. In this case, the waste water disposal of this city would be hindered.

The transport pipelines between Jutphaas and the dune area (1500 mm), over a distance of approximately 60 km, was constructed between 1954 and 1957. The transport pipeline trajectory was named WRK-I. The initial capacity was 76 Mm3/y. The surface water was pretreated at the Jutphaas facility with rapid sand filtration. Pretreatment was required in order to prevent fouling of the transport pipeline and to prepare the water for proper infiltration. In the 1970s, the pretreatment plant was expanded with coagulation and sedimentation. Later, in the 1980s the transport chlorination was abandoned in order to reduce the chlorine byproduct formation. The Jutphaas facility has several groundwater wells for back-up purposes, with a total capacity to compensate for a three month period in case the Lek-canal surface water does not meet the quality standards.

At Leiduin, a smaller pipeline splits off to transport water to the dune area of the drinking water company of the province of North-Holland (PWN) and the steel and paper industry.

### 7.2.4 The 1960s: doubling and adaptation of Leiduin

The dune facilities at Leiduin needed adaptation for the infiltration of river water. In 1957, the first river water was infiltrated in the dune area of Leiduin. In 1961, the capacity of Leiduin was doubled from 25 to 50 Mm3/y. In this period, some of the rapid sand filters are renewed, one of the sand filters is expanded with aeration, and the slow sand filter capacity was expanded. Also, in the early 1960s the facility was expanded with the dosing of powdered activated carbon (removal of organic pollutants) and chlorine (disinfection purpose).

### 7.2.5 Expansion of WRK

Even during the construction of the WRK pipeline project, and later during the first years of exploitation, it became clear that a second pipeline transport connection between Jutphaas and the dune areas would be necessary. In the mid-1960s, this WRK-II project was constructed by Gemeentewaterleidingen Amsterdam, via an alternative trajectory. The construction had two separate pipelines (1200 mm), and the Jutphaas facility was expanded. The additional WRK-II capacity amounted to 80 Mm3/y. The pipelines were connected to the dune area of Leiduin, the west side port area of Amsterdam and the industrial site north west of Amsterdam. The total production and transport capacity of the Jutphaas facility increased to 150 Mm3/y. In 2014, approximately fifteen large industrial clients use the WRK water in the west port area, such as concrete industry, juices and the waste processing energy company. In the near future, the prolonging of some of the larger WRK supply contracts will be reconsidered. The outcome of such negotiations may have considerable impact on the WRK exploitation.

### 7.2.6 Pipeline and storage adaptations in the 1960s

In 1961, the transport capacity between Leiduin and the city was improved with a new pipeline. In the west part of the city (Osdorp), a new booster station was constructed in 1961. In 1965, the maximum capacity of the Haarlemmerweg (also called Van Hallstraat) was reached. Therefore its facility was expanded with a water tower in 1966, and another storage and distribution facility was built in the south part of the city, at the Amstelveenseweg. Its water tower was also needed to balance pressure variations. Moreover, since the city had expanded to the south, the Haarlemmerweg storage facility was no longer situated in the center of the supply area.

All household pipelines, approximately 100.000 connections, were equipped with non-return valves in order to prevent water from the household installation to flow back into the distribution system. In this way, contamination of the drinking water system by eventually polluted water of the inner installation is prevented.

#### 7.2.7 Late 1960s: further capacity increase of Leiduin

In the early 1960s, the production capacity of Leiduin was just over 50 Mm3/y. After the construction of WRK-II was realized, it was necessary to increase the capacity of the extraction, the treatment and the pumping capacity of Leiduin. In 1968, the facility of Leiduin II was realized, making up for a total production capacity of 83 Mm3/y. At present, this still is the maximum production capacity of Leiduin. The fifth transport pipeline between Leiduin and the city was put into operation in 1968.

#### 7.2.8 The adaption of the Leiduin facility to its current configuration

In the 1980s, the Oranjekom facility (dunewater collection reservoir) was renewed. The existing facility had been operational over half a century, and it was kept as a back-up facility next to the new installation.

After an operation time of hundred years, and several expansions, the Haarlemerweg distribution pumping station was fully renovated in 1994.

The Leiduin facility was expanded with softening in the mid-1980s, for reasons such as customer satisfaction (comfort improvement) and reduction of soap- and energy usage. The Leiduin facility was further adapted, according to the Weesperkarspel approach, with ozonation and activated carbon filtration in 1995. As of that moment, the Leiduin treatment plant comprises aeration and rapid sand filtration, ozonation, pellet softening, activated carbon filtration and slow sand filtration.

Recently, the ozonation contact chambers were renovated. It is not expected that the Leiduin facility will need to produce at its maximum capacity. Therefore, only four out of five ozone contact chambers were renovated, and the fifth chamber is taken out of operation.

#### 7.2.9 Activated carbon filtration

The installation of activated carbon was initiated by the discovery of the presence of the herbicide bentazone in the drinking water. It was found that the chemical company BASF upstream in Germany was disposing waste water containing bentazone, to the river Rhine, which is the source (via the river Lek) for the Leiduin water. The BASF company stopped the disposal rather quickly, but it was decided to install activated carbon anyway in order to protect the drinking water against such pollutants. The Weesperkarspel plant was expanded with activated carbon prior to the Leiduin facility, since Weesperkarspel already had ozonation and its capacity was smaller, hence the project would fit in better in the time schedule.

#### 7.2.10 Dune infiltration and extraction system

The collection of the water, after infiltration, has always occurred in an open system. The investment in a closed abstraction system, in order to prevent contamination of the water after it has been purified during infiltration, has been considered a couple of times. However, the covering of the water abstraction requires the redesigning of the entire system and is accompanied with very high investment costs. The current existence of the infiltration and subtraction dune site is a result of the subsequent developments of capacity expansion and adaptation of the dune functioning. Most probably, the dune site would have been designed and built differently if it was built all at once in the present time.

Additionally, it seems that the functions of dune infiltration of the modern drinking water supply have changed. Initially, original dunewater was abstracted because of its excellent water quality. Decades later, the dunewater storage needed to be replenished with pretreated river water in order to prevent the upconing of brackish water and to prevent the irreversible depletion of the deeper aquifers. Nowadays, the advantages of dune infiltration can be summarized as follows:

- Natural virus and bacteria removal
- Capacity buffering and smoothening of water quality as well as temperature.

## 7.3 Weesperkarspel

The Leiduin facility was not able to handle the growing water demand in Amsterdam at the end of the nineteenth century. Therefore it was decided to build a second treatment in the town formerly known as Weesperkarspel, about 10 km southeast of the city. In 1888 the Weesperkarspel production plant was completed. It was named after the former municipality in the same location. It originally had a water tower, which was dismantled in 1910. The water was transported to the city via two transport pipelines. The Dunewater Company was forced by the city council to execute the entire project.

### 7.3.1 Vecht water for cleaning purposes

The water of the river Vecht was the initial source for Weesperkarspel. The Vecht water could not qualify as drinking water, despite the treatment. The Vecht water suffered from high salt contents and the waste water of the upstream towns, such as the city of Utrecht. The treatment comprised sedimentation and slow sand filtration. In the period after the start-up, knowledge of large scale, sophisticated drinking water treatment was lacking, and so was knowledge of waste water treatment. Because of its inadequate quality, the Weesperkarspel water was distributed in a pipeline network separated from the dune water network. The water was mostly used for cleaning purposes and firefighting. Hence, in these days, the city of Amsterdam had two separated distribution network systems.

### 7.3.2 Search for new sources

Because of the high salt contents of the river Vecht, it was decided in the beginning of the 21st century to switch to an alternative source. Around 1915, the Merwede canal water was treated at Weesperkarspel. The quality of the Merwede water proved not to be sufficient either, mostly due to shipping activities. In 1920, both sources were alternatingly used. In this period, research was conducted to the applicability of new sources, such as the rivers Lek, Rhine and Waal, several lakes (lake Loenderveen and lake Loosdrecht), as well as the usage of reclaimed water from the Bethune polder. In 1928, lake Loenderveen was partly acquired for drinking water purposes, after ever increasing signals about further land reclamation in its area and the usage of the lake for waste dumping purposes. Hereafter, the lake was held for natural reserve purposes as well.

### 7.3.3 The 1930s: lake water as source and adaptation of treatment

In 1929, plans to rebuild the Weesperkarspel plant from a river water to a lake water treating facility were put to practice. There were plans to gradually expand the capacity from 6 to 30 and eventually even to 60 Mm3/y. It was decided to build the 30 Mm3/y option. The water was subtracted from the lake Loenderveen, which, by doing so, is partly replenished by water from lake Loosdrecht and reclaimed water from the Bethune polder. Water from this lake was suitable because the lake had been shut down for (recreational) shipping. Rapid sand filters were placed between the sedimentation and the slow sand filters in 1926, and the water was disinfected with post-chlorination. In 1932, the treatment gradually switched to the new source water quality in order to make the filtration respond well to the new water quality.

The switch to the new source led to different problems, such as the growing of mussels in the transport pipeline between lake Loenderveen and the treatment plant of Weersperkarspel. This was mainly caused by the high phosphate content of the lake water.

### 7.3.4 Weesperkarspel water for drinking purposes

The introduction of lake water meant the end of the salt problem in the Weesperkarspel drinking water, and the water quality significantly improved. Therefore, the separation of the distribution networks could slowly disappear and the double network ceased to exist in 1939. After many decades during which the water was found inadequate for drinking water purposes, the Weesperkarspel water seemed to be accepted. Probably because of the improved water source and trust in water treatment, the limitations of the dunewater extraction and the lower costs of the water due to the fact that the water was produced with existing infrastructure.

### 7.3.5 Graduate capacity expansion and temporary return to river water

In the 1930s, the operation of the rapid sand filters was improved by replacing the sand with a courser type, and introducing a new type of backwashing system with air and water. The number of slow sand filters was increased from four to six. The capacity of drinking water storage was expanded.

After the invasion of the Germans in World War II, it was decided to inundate the lakes with water from the river Vecht for strategic protection purposes. Therefore, the treatment plant had to switch back temporarily to the usage of Merwede water. Lake Loosdrecht was inundated with Vecht water, but luckily its salt content had improved over time. Just before the capitulation of the Germans, they destroyed the locks in the Vecht river. Again, the lake water was polluted with river water and the water production was depending on the Merwede source for a short time.

The capacity of Weesperkarspel was further increased in 1941 by the installing of two more slow sand filters. Also, a new disinfection installation was put into operation.

### 7.3.6 The 1950s: further optimization of pretreatment

In 1948, a plan was made for the separation of a part of lake Loosdrecht. Due to this separation the protection of the source water would improve. Also, this part of the lake could be dug out deeper, which would be favorable to the water quality (less color). In the 1950s, the “drinking water lake” and the “drinking water canal” were brought into operation. In this way, a system for drinking water purposes was created, separated from the surrounding lakes by the construction of an enclosing dike. The separation was important because the surroundings got more polluted due to waste water disposal, agricultural activities and recreation. The drinking water lake functions as a first purification step, due to the residence time, as well as limited storage. The drinking water canal transports the seepage water extracted from the Bethune polder directly to the drinking water lake, rather than disposing and extracting the water via lake Loosdrecht. These adaptation led to a further improvement of the raw water quality.

Despite the isolation of the source water, the treatment plant experienced some problems. The water was colored due to the presence of organic matter, and the slow sand filters needed frequent cleaning because of the clogging with algae. The growth of algae was caused by the high phosphate concentration of the lake water. Research tests with ozone were performed to study the removal of color. Both the color of the water and the taste caused by the chlorination led to customer complaints. The hydrological circumstances of the Bethune polder and the drinking water canal were improved. However, these measures could still not lead to the required water quality and the desired production capacity.

The drinking water lake was expanded with dosage of the coagulation salt ferric chloride. This removed a significant amount of phosphate, the algae growth was limited and the slow sand filters needed to be cleaned less frequently.

#### 7.3.7 Search for an additional source

Due to water quality and filter clogging problems, the annual production of Weesperkarspel still lagged the desired capacity. New plans were made for expanding the plant, from 25, to 31 and finally to 60 Mm3/y. To reach such capacities, several additional water sources were investigated since the Bethune polder alone would not be sufficient. The river Vecht as well as the Amsterdam – Rhine canal were considered. The latter was less polluted than the first, due to waste water disposal of villages and the city of Utrecht upstream in the Vecht, but also because of its constant flushing with river Lek water. The canal water quality was not adequate for direct disposal in lake Loosdrecht, therefore its water would need pretreatment. With this facility, the drinking water production would obtain an alternative water source, and the water quality of lake Loosdrecht would improve as well. A second improvement of lake Loosdrecht water quality was obtained because several municipalities decided to install sewer systems and waste water treatment plants.

#### 7.3.8 The 1970s: rebuilding Weesperkarspel treatment plant and adaptation of the pretreatment

The Weesperkarspel treatment plant was completely renewed in 1977, and the former facility was demolished. The process configuration was expanded with ozonation and coagulation. The purposes of the ozonation were disinfection, removal of color and improvement of taste. The organic matter was removed after ozonation, in the coagulation and rapid sand filtration. Dosing of powdered activated carbon was optional. The ozonation replaced the chlorination, after it was shown that chlorination causes formation of harmful byproducts. The pretreatment of the water, prior to further treatment at Weesperkarspel was important for the efficacy of the ozonation process. In the winter of 1976, the open slow sand filters froze for the last time. In 1977, these filters were put out of operation, and they were replaced with modern, covered filters.

The pretreatment site was adapted in the mid-1970s. The surface water was treated with rapid sand siltation (covered) after the drinking water lake, and prior to transport to the Weesperkarspel plant. Due to this additional treatment, the fouling of the transport pipeline between the pretreatment and the Weesperkarspel plant was limited, and the amount of ozone needed for the oxidation of organic matter could be reduced.

#### 7.3.9 The 1980s: Realization of alternative source

In the early 1980s, the pretreatment was expanded with an additional separate coagulation step, prior to the drinking water lake. Also, in this period, the possibility for the intake of Amsterdam-Rhine canal water was realized. The connecting of this alternative source was meant for expanding purposes in case the capacity of Weesperkarspel would actually be doubled to 60 Mm3/y. Such an increase would not be possible merely with Bethune water. Initially, the river water intake was planned to be equipped with a separate phosphate removal installation. However, the used capacity of the canal water has always been limited because of the stabilization of the water demand. In 2014, it functions as a back-up surface water source. Therefore, such separate coagulation installation for canal water treatment has never been realized. The sporadic intake of the canal water is mixed with the lake water and occurs through the existing pretreatment facilities.

#### 7.3.10 The 1980s: stop post-chlorination and start softening

In the early 1980s, the post-chlorination was stopped after full-scale tests had proved that the drinking water could be distributed as such without compromising drinking water quality.

In the late 1980s, the Weesperkarspel plant was expanded with softening. The incentives for softening were increasing customer comfort due to lower potential for salt precipitation, the reduction of soap usage, and the reduction of energy usage due to a better heat transfer in warm water equipment. Additionally, an incentive for softening was the reduced emission of copper and lead from piping materials, which was favorable for public health and the environment.

#### 7.3.11 The 1990s: activated carbon filtration

Due to the improvements of analytical methods, traces of the herbicide bentazone in water were discovered in 1987. This led to an adaptation of the treatment plant once more. The coagulation and rapid sand filtration of the Weesperkarspel plant were replaced with activated carbon filtration in 1993. In addition to the removal of organic micro pollutants such as bentazone, the activated carbon reduces biologically removable organic matter that is formed during ozonation.

#### 7.3.12 Adaptations to ozonation

In the 1990s, it is found that the carcinogenic compound bromate is formed as a byproduct in ozonation. The 2001 Drinking Water Decree contains maximum standards for bromate. Also, the revised Decree contains a new approach for the assessment of the bacteriological safety of drinking water, the so called quantitative microbiological risk assessment. In the beginning of the 21st century, it was found that the water was polluted with pathogenic bacteria. These bacteria were introduced in the water by the feces of birds residing near the drinking water lake during winter time. Both occurrences led to thorough research programs aimed at the improvement and optimization of the ozonation. Several plant changes were made during the last decade in order to maximize disinfection purposes while limiting the bromate formation at the same time.

In 2014, the pretreatment at Loenderveen comprises coagulation and sedimentation, the drinking water lake and rapid sand filtration. Next, the pretreated water is transported to the Weesperkarspel plant, comprising ozonation, pellet softening, activated carbon filtration and slow sand filtration.

### 7.4 Plans for expansion through the years

Since the 1930s, plans were made for the expanding of the Weesperkarspel plant, to double the current capacity to 60 Mm3/y. In the 1980s, it was estimated that under certain circumstances, the annual total production of Weesperkarspel plus Leiduin might increase from 86 Mm3/y in the year 1988 to over 130 Mm3/y in the year 2000. The expansion plans comprised the capacity increase of the Amsterdam-Rhine canal pumping station, additional transport pipelines at the pretreatment plant, a second flocculation installation at the pretreatment, the realization of the second drinking water lake, the increase of the pumping capacity of the pretreatment, and, concerning the Weesperkarspel treatment plant, the expanding of the ozonation, the softening, the activated carbon filtration, the slow sand filtration drinking water storage and distribution station. The rapid sand filters at the pretreatment plant already had been built in a redundant way. In order to take advantage of the excess capacity, the sand fraction was decreased, leading to a better water quality.

The spatial planning of the Weesperkarspel site has always been prepared for such an expansion. Also, the required environmental impact assessment procedures were prepared at that time, but were stopped in the late 1990s. The same holds for the application of ultrafiltration for pretreatment purposes: this technology was investigated for expanding applications of the pretreatment, but the research was stopped in the same period. Reservations were made for the second drinking water lake, having implications for recreational usage. However, concerning the current water demand, after its stabilization at the end of the 20$^{th}$ century, in 2014 the investing in such a capacity increase is no longer expected to be necessary for the urban area of Amsterdam.

## 7.5 Amsterdam in general

Hereafter, some general developments for the city of Amsterdam are described. These developments are not directly linked to either the Leiduin or Weesperkarspel facility.

As of 1896, Amstelveen, a neighboring municipality of Amsterdam, was served with water produced from a groundwater production site at Hilversum. This facility was shut down because of water quality problems and its small scale. The groundwater was polluted with grease solving compounds (tri), and despite the installation of an activated carbon filtration it was decided to close the facility in the late 1980s.

The district of IJburg was equipped with a doubled piping system, in order to be able to supply both drinking water and household water (grey water). The development of the grey water market were forced to stop by the government after cross connections between the drinking water and the household piping systems led to incidents concerning public health.

Until 1999, the household water consumption was not metered in Amsterdam. In 1999, the city council forced the Gemeentewaterleidingen to start metering. In 2014, approximately 70% of the households is equipped with a water meter, and it is expected that it will take about twenty years to complete the project.

The Schiphol airport is the largest client of Waternet, and the airport is growing well the past decades. During its development, the Gemeentewaterleidingen helped to develop the drinking water mains, which were handed over to Schiphol after construction was realized. Because of the development of the airport, Waternet had to reconstruct one of its large transport pipelines.

The water usage per inhabitant has always been high in Amsterdam in comparison to other cities. Three possible reasons might explain this observation: the city did not have water meters until recently, the average number of inhabitants per household is low compared to other cities, and the ratio between native and foreign people is high compared to other cities.

The Gemeentewaterleidingen Amsterdam is one of the last Dutch drinking water companies that has built water towers. In 2014, still two water towers are operational. The main drinking water structure of the Weesperkarspel and Leiduin production facilities and their transport connections to the city have gradually expanded in capacity, but the structure outline has not had significant changes through the years.

Waternet controls the pressure in the distribution network in such way that standards are just met. In such way, the company is able to save energy and the pressure load to the piping material is lower, which is thought to be favorable for the lifespan. The water meters used are of the velocity-type, rather than the volume-type. In the Netherlands, most water companies tend to choose the volume-type water meters (status 2014). Waternet prefers the velocity-type, since this device has smaller pressure losses. Also, Waternet designs its own household pipeline connections, aimed at a minimum pressure loss.

## 7.6 References

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Waternet Drinkwaterplan 2010 – 2015, https://www.waternet.nl/media/88327/waternet_drinkwaterplan.pdf

## 7.7 Interviews

Period: October – December 2013.

- Eric Baars
- Marco Dignum
- Arne Bosch
- Alex van der Helm
- René van der Aa

# 8 Driver analysis and discussion

## 8.1 Classification of drivers

The historical development of the infrastructure of four cities was described in the previous chapters. The reason or incentive behind all investments was identified. To make the results for the four cities comparable and more compact, these reasons and incentives were clustered into the classification of drivers as presented in Table 2.

TABLE 2; DRIVER CLASSIFICATION (DRIVER CODES ARE REFERRED TO IN TABLE 3 - TABLE 6)

| Driver code | Driver description |
|---|---|
| WQ | Water quality (raw water or drinking water quality) |
| AVB | Availability of source water (related to capacity or quality) |
| WD | Water demand or production / distribution capacity |
| SEC | Security of supply (related to water demand)[2] |
| P | Water pressure in the distribution net |
| SUP | Water supply plan |
| GEO | Geographical or climate related factors |
| POL | Governmental or provincial policies, laws, or Water Decree |
| 3rd | Influenced / imitated by third parties |
| CUST | Customer related |
| SCAR | Scarcity of materials |
| DEP | (In)dependency of other parties |
| TECH | Technological development, the availability of new technology |
| RNV | Renovation (because of age, or rate of failure ) |
| € | Costs |
| PLAN | Investment- and project planning / timing |
| HIST | Dependency of historical infrastructure (continuation of existing infrastructure) |
| CONTR | Contracts with clients or other parties |
| OP | Operational reasons |
| ORG | Organizational (mostly related to merger and acquisition) |
| IMG | Image (or customer confidence) |
| E | Energy (cost related) |
| ENV | Environment, sustainability |

The description of the four cities was transformed to one table for each city. The described reasons and incentives for investing were transformed to one or several drivers from the classification. Table 3 - Table 6 summarize the investments, the description of the drivers for the investment, the driver-classification and the period of investing, for all four cities. The table also relates investments to the sphere of influence (internal, transactional or external). The indication of the sphere of influence was made by a quick judgment rather than

[2] Security of supply concerns the number of customers that is shut down from the centralized water supply for a certain amount of time after an interruption of water production or water supply. In the Netherlands, this parameter has been of great importance since many decades, and demands regarding the minimum level of security of supply is integrated in the Dutch Drinking Water Decree around 2000. It was not possible to always clearly distinguish between the drivers ‘water demand’ and ‘security of supply’ while assessing the information obtained from literature and interviews.

thoroughly studying each investment decision. The sphere of influence judgment was based on the type of investment and the driver behind the investment. In some cases, a strong correlation can be found between the sphere of influence and the driver, for instance geographical factors are mostly indicated as ‘external’, as well as investments because of an increasing water demand. Policy or third party driven investments could both be regarded as external or transactional influences, and therefore the judgment is complicated in some case, However, an accurate assessment of the sphere of influence for all 225 investments is beyond the scope of this research.

Occasionally, the tables contain occurrences – rather than investments – that played an important role in the development of the drinking water company (such occurrences are marked blue). Also, the table mentions when facilities or installations were shut down, because the shutting down of assets – in addition to the building or renovation of assets – is of importance for the development of the infrastructure as well. Very often, the shutting down of one asset can directly be related to the investment in another asset.

## 8.2 Drivers for infrastructural developments Groningen

The following drivers can be identified from the historical developments of the infrastructure of the urban area of Groningen.

TABLE 3; DRIVERS HISTORICAL DEVELOPMENT DRINKING WATER INFRASTRUCTURE GRONINGEN (DRIVER CLASSIFICATION CODES REFER TO TABLE 2).

| Year | Investments or occurrence | Driver | Classification driver | Internal/ Trans/ External |
|---|---|---|---|---|
| 1880<br><br><br><br><br><br><br><br><br>1923<br>± 1930 | ▪ Determining type and location of drinking water source.<br>▪ Investments in drinking water treatment (adaptation, expansion, optimization), in order to remove different kinds of substances (e.g. macro-ions, particles, esthetic parameters, microbiological).<br><br>For instance:<br>▪ Rapid sand filtration<br>▪ ozonation | Water quality demands | WQ | EX<br><br>IN |
| 1880 - 1940 | ▪ Several expansions of different facilities:<br>Extraction, treatment, storage capacity, and transport pipeline capacity.<br>▪ Construction of new facility | Increasing water demand | WD | EX |
| ± 1890 | Construction of sag pipe systems | The presence of infrastructure of other parties (e.g. canals) | 3rd | EX |
| ± 1900 | | Customer complaints on taste and odor | WQ<br>CUST | TR |
| 1911 - 1918 | Establishment of a new water company Including its required facilities such as catchment, treatment, transport and distribution.<br>Leading to double distribution systems in some parts | ▪ Disagreements on water service concessions<br>▪ Relationship between two water companies | ORG | TR |
| 1947 | Reconstruction | Damage during war | RNV | EX |
| ± 1930 | ▪ Groundwater wells<br>▪ Additional filtration<br>▪ Mixed treatment | Discovery of groundwater (abundant and good quality) | WQ<br>AVB | IN<br>EX |
| ± 1935 | Covering of facilities | ▪ Prevent growth of algae | WQ<br>OP | EX |

| | | | | |
|---|---|---|---|---|
| | | ▪ Increase time between cleaning | | |
| ± 1965 | Shut-down of ozonation<br>Investment in chlorination? | Control microbiological drinking water quality in alternative manner | TECH<br>WQ | IN |
| ± 1960 | Adaptation treatment | Pollution of source water | WQ | TR |
| 1973 | Restore surface water treatment capacity | Improve protection of source water | WQ | TR |
| ± 1970 | Operational adaptation of water treatment | Low water temperatures in winter | GEO | EX |
| ± 1970 | Constant improvement of treatment | Decrease dependence treatment performance of raw water quality changes | WQ | TR |
| 1945 - 1970 | Construction of groundwater wells | Search for new sources | AVB | IN |
| 1971 | Renovation, and expanding of extraction, treatment and pumping capacity | Water demand | WD | EX |
| 1960 - 1970 | Construction of groundwater wells (Haren) | Compensation of reduced capacity of other facility because of its renovation | WD | IN |
| 1959 | Renovation | Condition of facility and installation after producing for decades | RNV | IN |
| 1930 | Establishment of provincial drinking water company (comprising several production facilities) | Public health | ORG | TR |
| ± 1965 | provincial water company:<br>▪ Construction of new facilities<br>▪ Adaptation/expansion/preparing of existing facilities | Expected increase of water demand | WD | EX |
| ± 1990 | Investment in researching the possibilities of ultrafiltration for direct surface water treatment | Expected changing raw water quality, development of quality standards and availability of new technology | TECH<br>WQ<br>POL | EX |
| Entire period | *Several projects* | Reliable water supply | SEC | TR |

| | | | | |
|---|---|---|---|---|
| ± 1975 - 2005 | Investment in deep infiltration of drinking water | ▪ Secure water supply<br>▪ Stimulation by policy makers<br>▪ Prevent upconing of brackish water<br>▪ Water quality improvements | WD/SEC<br>POL<br>WQ | TR<br>EX |
| ± 1980 | Investment in trees reduces mixing in sedimentation and leads to optimized treatment step | Water quality improvement in treatment | WQ | GEO |
| ± 1980 | Investing in cover of outdoor coagulation reservoirs<br>After it got clear that surface water treatment still was a solid option, since source water quality improved further because of regulations and agreements on groundwater usage reduction | ▪ Waste water discharge regulation<br>▪ Agreements on reduced groundwater usage<br>Leading to improved source water quality<br><br>▪ Reduce outdoor influences on water quality | POL<br>WQ<br><br>GEO | IN, TR, EX |
| ± 1960 - 1970 | Separation of surface water and groundwater treatment | Progressive insight and increase of groundwater usage | AVB<br>WQ | IN |
| ± 1995 | Construction of mixing reservoir leads to smoothing of quality | ▪ Large quality variations of source water<br>▪ Pesticides found in source water | WQ | IN |
| 1985 | Construction of activated carbon | Pesticides found in source water | WQ | EX |
| 1985 | Construction of activated carbon configuration is known not to be the best option | Technical and financial boundaries | €<br>TECH | IN |
| ± 1980 | *Occurrence rather than investment*<br>Confirmation that groundwater is needed ad source (justification of investments) | Large variations in flow of surface water, little storage capacity of raw water | WQ<br>AVB | EX |
| 1988 | Shut-down of post-chlorination | Discovery of harmful disinfection byproducts | WQ | TR |
| 1998 | *(occurrence rather than investment):* | ▪ Stagnation of | ORG | TR |

| | | | | |
|---|---|---|---|---|
| | Merger of municipality and provincial water company | growth of service areas and water demand, leading to expected increase of water price<br>▪ Legal statement regarding the minimum size of drinking water company | | |
| ± 1999 | Shut-down of membrane filtration research | ▪ Costs<br>▪ Different perspectives regarding membrane filtration and preference for groundwater treatment | € | IN |
| ± 2000 | Reinvesting in surface water treatment | ▪ Agreement on reduction of groundwater extraction<br>▪ Efforts on surface water quality improvements have turned out successful<br>▪ Reliable water supply | POL<br>WQ<br>SEC | IN |
| ± 2005 | Shut-down of deep infiltration | ▪ Costs (small capacity and need for renovation)<br>▪ Capacity<br>▪ Security of supply | €<br>SEC | IN |
| ± 2011<br>Future | ▪ Shut-down of one smaller ground water facility<br>▪ Considering to shut down a second facility | ▪ Preference for surface water<br>▪ Possibility for purchase of drinking water | WD<br>€ | IN |
| 2005 | Installation of UV disinfection and temporary chlorination | Campylobacter contamination | WQ<br>TECH | IN |
| 2012 | Revamp of UV installation | Biologically | WQ | IN |

| | | | | |
|---|---|---|---|---|
| | | unstable drinking water | | |
| 2012 | Investment in redundancy | Reliable water supply | SEC | TR |
| 2000 | Dismantling treatment building | Original design has never worked properly | RNV | IN |
| ± 2000 | Relining or transport pipeline | Serious problems at highway caused by leakage | IMG<br>€ | IN |
| Future | Possible large adaptation of transport pipeline system | ▪ Risk for damage to third party property<br>▪ Plans of third parties to broaden the highway | IMG<br>€ | TR |
| 1880 – 1930 | Adaptation of transport- and distribution network system | Keeping sufficient pressure after increase of water demand | P | IN |
| 1908 | Construction of water tower | Construction of new hospital | 3rd | TR |
| Recent | Shut-down of water towers<br>Construction of storage reservoirs | ▪ Limited storage capacity of water towers<br>▪ Progressive insight regarding storage and distribution | TECH<br>WD | IN |
| 1998 - present | Construction of connections between municipal and provincial distribution network | Integral consideration of reliability of water supply after merger | P<br>SEC<br>WD | IN |
| 1998-present | Pressure reducers installed between municipal and provincial distribution network | City has always operated at lower pressures. Geographically and historically determined | GEO<br>HIST | IN |
| ± 1970 | ▪ Construction of transport pipeline<br>▪ Purchase of land (for facility development purposes) | Rapid expected increase of water demand of new port | WD | IN<br>EX |

## 8.3 Drivers for infrastructural developments Arnhem-Nijmegen

The following drivers can be identified from the historical developments of the infrastructure of the urban area of Arnhem and Nijmegen.

TABLE 4; DRIVERS HISTORICAL DEVELOPMENT DRINKING WATER INFRASTRUCTURE ARNHEM-NIJMEGEN (DRIVER CLASSIFICATION CODES REFER TO TABLE 2).

| Year | Investments or occurrence | Driver | Classification driver | Internal/ Trans/ External |
|---|---|---|---|---|
| | | | | |
| **ARNHEM** | | | | |
| | | | | |
| 1885 | Construction of high reservoir rather than water tower | ▪ Costs<br>▪ Geographical situation | €<br>GEO | IN<br>EX |
| ± 1909 | ▪ Construction of reservoir<br>▪ Construction of pumping facility<br>▪ Construction of water tower | Keep water pressurized during increasing water demand | WD<br>P | EX |
| ± 1910 | Change function of facility from operational to back-up and finally shut-down | Water quality raw water | WQ | EX |
| 1940 | ▪ Temporary shut-down of district<br>▪ Construction of temporary facility<br>▪ Repair of transport pipeline | Destroying of bridge and pipeline during war | 3rd | EX |
| ± 1945 | Repair | Damaging of water tower and facility during war | 3rd | EX |
| ± 2000 | Shut-down of transport pipeline | Poor condition | RNV | IN |
| ± 1945 | Construction of sag pipes | Connect both river sides (north and south) of city | GEO<br>WD | TR |
| ± 1940 | Construction of pipeline and booster station | Forced airport adaptation by invaders during war | 3rd | EX |
| ± 1940 | Construction of booster station | Change of water supply plan | SUP | IN |
| ± 1950 | ▪ Construction of additional high reservoir<br>▪ Construction of booster | Increasing water demand | WD | EX |
| ± 1950 | Switch from phreatic to deeper extraction | Unknown, but guess is availability of new pumping technology, need for additional groundwater, | TECH?<br>WD?<br>WQ? | EX<br>IN |

| | | | | |
|---|---|---|---|---|
| | | water quality | | |
| 1953 - 1958 | Renovation of existing treatment facility | Condition | RNV | IN |
| 1968 | Construction of additional wells | ▪ Increasing water demand<br>▪ Obtained extraction permit | WD<br>POL | EX<br>TR |
| 1978 | Construction of new booster | Improve water supply | SUP<br>P | IN |
| 1980 | Construction of new facility<br><br>*(Location moved from north to south)* | Current facility cannot meet required water demand<br>*(spare groundwater at natural reserve area)* | WD<br><br>*(POL)* | EX<br><br>*(TR)* |
| ± 1985 | Expansion of facility capacity | Increasing water demand | WD | EX |
| 1985 | Renovation facility | Poor condition due to long period of intensive usage | RNV | IN |
| ± 1970 | Install rapid sand filtration | Iron removal | WQ | IN |
| ± 1985 | Install marble filtration for condition of water | Prevent damaging of cement distribution pipelines | €<br>WQ | IN |
| 1930 – 1960 | ▪ Growth of number of shallow wells<br>▪ Graduate switching from shallow to deeper extraction<br>▪ Graduate decrease of number of wells | ▪ Increasing water demand<br>▪ Technological possibilities<br>▪ Water quantity and quality | WD<br>TECH<br>AVB<br>WQ | EX<br>IN |
| ± 2000 | Construct catchment basin for run-off water | Protect raw water quality | WQ | TR |
| ± 2000 | Integral optimization of water cycle, e.g. extraction at two facilities | ▪ Protect nature reserve of Veluwe<br>▪ Shortage of groundwater during low river levels | POL<br>GEO | TR |
| ± 1950 | Construct additional reservoir | Growth of city and growth of water demand | WD | EX |
| ± 1990 | Expand filtration capacity to reduce | Customer | WQ | TR |

| | | | | |
|---|---|---|---|---|
| | filtration velocity | complaints on brown water | CUST | |
| ± 2000 | Repeatedly decided not to invest in softening | ▪ Costs and priority<br>▪ Customer satisfaction | €<br>CUST | IN |
| Entire period | Divide distribution system into pressure zones | ▪ Meet pressure standards<br>▪ Limit energy usage<br>▪ Prevent failure distribution system | P<br>E<br>€ | IN |
| ± 2010 | Shut-down (closing) of sag pipes | Change of water supply plan | SUP | IN |
| Future? | Investments for pressure increasing equipment needed (by other parties) in apartment buildings | Reduce high pressure for various reasons by water company is considered | P<br>E<br>€ | IN |
| 1991 | Acquisition of water company by private party | Targets, ambition and enterprise plans | ORG | TR |
| | | | | |
| **NIJMEGEN** | | | | |
| | | | | |
| 1879 | Choice of facility location | Close to customers | GEO | IN |
| 1879 | Construction of high reservoir rather than water tower | ▪ Need for water storage<br>▪ Geographical situation | SEC<br>GEO | EX<br>IN |
| 1909, 1920<br><br>1940 | ▪ Repeated expansion of facility capacity<br>▪ Construction of second facility | Growing water demand | WD | EX |
| ± 1995 | Install marble filtration for condition of water | Prevent damaging of cement distribution pipelines | €<br>WQ | IN |
| 1985 | Expand facility with water treatment | ▪ Shut-down of two large groundwater extracting parties (paper industry), leading to raw water | 3rd<br>WQ<br>POL | EX |

| | | | | |
|---|---|---|---|---|
| | | quality changes<br>▪ Drinking water quality not compliant with future drinking water standards | | |
| ± 1980 | Testing and installation of air stripping | Groundwater pollution | 3rd<br>WQ | EX |
| 1985 | Overdesigning air strippers | Expected drinking water standard was lower than actual standard | POL | EX |
| 1985 | Expanding with softening | Customer satisfaction and adaptation of hardness to the hardness of the other facility | CUST | IN |
| 1988 | ▪ Reduce extraction and compensate with extraction at other site<br>▪ Restore capacity of polluted site<br>▪ Construction of partial activated carbon filtration. And later: construction of transport pipeline for raw water transport and mixing of two different water sources. | ▪ Discovery of herbicide bentazone in raw water<br>▪ Limit permitted groundwater extraction<br>▪ Redundancy<br>▪ Costs (scale-up?) | 3rd<br>WQ<br>POL<br>SEC<br>€ | EX<br>TR<br>IN |
| 1990s | Renovation and install automation | • Operational for long period, poorer condition.<br>• Manual operation leading to higher energy and water usage. | RNV<br>€ | IN |
| Future | Future investment in additional transport pipeline to Waalsprong district to compensate for absence of household water | Backlash of household water market (forbidden by government). Need for additional drinking water | 3rd<br>POL<br>WD | EX |

| | | | | |
|---|---|---|---|---|
| | | instead. | | |
| | | | | |
| **ARNHEM-NIJMEGEN AREA** | | | | |
| | | | | |
| ± 2002 | *Occurrence rather than investment, but leading to a change of planned investments:*<br>Isolated systems become part of larger system. Water distribution plan is considered integrally, on a city-exceeding scale. This leads to adaptation of the drinking water infrastructure of the city. | Merger of isolated and autonomic municipalities to larger scale provincial companies | ORG<br>SUP/SEC<br>€ | IN |
| ± 2002 | *Occurrence rather than investment, but leading to a change of planned investments:*<br>The larger, or stronger, or more influential company may change the existing investment plans of the other company. Or investment plans of both companies are changed because of renewed integral considerations.<br><br>Changed investment plans comprise:<br>▪ Expand treatment facility and transport additional groundwater from other sites<br>▪ Cancel the planned investment in a new facility at the latter sites<br>▪ Serving of Achterhoek region<br>▪ Serving of Nijmegen and Arnhem, leading to adapted pressures in certain districts | Merger of companies<br><br>In this specific case:<br>▪ Different insights<br>▪ New, larger scale of operation<br>▪ Desire for scale-up | ORG<br>SUP/SEC<br>€ | IN |
| ± 1995 | Investment in backwash water installations | Agreement with policy makers on prevention of soil pollution | POL | TR |
| ± 2006 | ▪ Shutting down smaller facilities in Achterhoek region<br>▪ Compensation by transport of drinking water via newly constructed pipeline works<br>▪ Construction of softening plants, clustered treatment<br>▪ Decided not to invest in the purchase of drinking water | ▪ Serve softer water<br>▪ Scale-up by clustering and shutting-down smaller facilities<br>▪ Reduce dry-out of soil<br>▪ Self-sufficiency | CUST<br>SUP/SEC<br>ORG<br>€<br>DEP | IN |
| ± 2005 | Transport pipeline construction for drinking water transport | Sparing of natural reserve, leading to reduction of | POL | TR |

| | | | | |
|---|---|---|---|---|
| | | groundwater extraction permit | | |
| ± 2000 | ▪ Infiltration facilities<br>▪ Change to deeper aquifers | Sparing of natural reserve, reduce dry-out of soil | POL | TR |
| 2002 - Future | ▪ Reduction of permitted extracted groundwater<br>▪ Shut-down of facilities and optimization of other facilities | ▪ Inhibit development of third parties<br>▪ Overcapacity (number of extractions and annual permitted capacity) | 3rd<br>POL<br>SUP/SEC<br>€ | TR<br>IN |

## 8.4 Drivers for infrastructural developments Maastricht

The following drivers can be identified from the historical developments of the infrastructure of the urban area of Maastricht.

TABLE 5; DRIVERS HISTORICAL DEVELOPMENT DRINKING WATER INFRASTRUCTURE MAASTRICHT (DRIVER CLASSIFICATION CODES REFER TO TABLE 2).

| Year | Investments or occurrence | Driver | Classification driver | Internal/ Trans/ External |
|---|---|---|---|---|
| 1880 | Extraction, pumping and distribution facilities | ▪ Establishment<br>▪ Water demand | WD | EX |
| 1886 | Under water pipe | Connect both sides of river | GEO<br>SEC<br>AVB | EX |
| ± 1916 | Search and test new extraction facility | Development of other towns | 3rd<br>WQ<br>WD | EX |
| 1918 | Acquire extraction site | Future development plans | WD<br>SEC | IN |
| 1921 | New production facility on other side of the river | ▪ Water demand<br>▪ Water pressure<br>▪ Desire for facility on west side | WD<br>P<br>GEO | EX<br>IN |
| 1926 | Chlorination | Public health | WQ | IN |
| 1920 | Damage and repair of production facility | ▪ River flooding<br>▪ Security of supply | GEO<br>SEC | EX |
| 1925 | Construction of new production facility | Customer complaints about water quality and continuity | SEC<br>WQ<br>CUST | EX |
| 1925 | Sell production facility to industry | New facility available | AVB | IN |
| 1886 | High reservoir constructed at hill | Water demand and continuity | GEO<br>SEC | EX |
| 1932 | New reservoir | ▪ Security of supply<br>▪ Energy cost reduction | SEC<br>€ / E | EX<br>IN |
| 1927 | Construction of new wells | Research availability of deeper groundwater on the west side of the river | WQ<br>AVB | IN |

| | | | | |
|---|---|---|---|---|
| ± 1930 | ▪ Sell mineral source well to private enterprise<br>▪ Renovation of existing facility | Deeper groundwater was of no use for drinking water purpose | WQ<br><br>WD | EX |
| 1945 - 1960 | Fix bore well of private party | Contamination groundwater with brackish mineral water | 3rd<br>WQ<br>SEC | EX |
| 1960 | Shut-down of production facility | ▪ Water quality, situated in city center<br>▪ Availability of alternative production site | AVB<br>WQ | IN |
| 1930<br>1950 | ▪ Purchase of site for extraction tests<br>▪ More extraction tests | Search and test alternative sources, on the west side of river | WD<br>SEC<br>AVB | IN |
| Entire period | Extraction of groundwater | Avoid high groundwater levels and nuisance | GEO<br>CUST | IN → TR? |
| ± 1945 – 1950<br><br><br><br><br>1945 | *Occurrences/actions*<br>▪ Water supply planning<br>▪ Limit waste of drinking water<br>▪ Agreement with private parties on supporting water supply<br><br>Additional well | ▪ Water demand increases<br>▪ Existing facilities reach limits | WD<br>SEC | EX |
| ± 1950 | Adapt transport pipeline | ▪ Security of supply<br>▪ Outside temperature conditions | GEO<br>SEC | EX |
| 1950 and further | Construction of deeper wells | ▪ Technological development new pumps<br>▪ Higher costs of former extraction<br>▪ Extraction by different water company | TECH<br>€<br>3rd | EX |
| 1949 | New transport pipeline | Security of supply | SEC | IN |
| 1953 | ▪ Construction of new facility<br>▪ Raw water treatment | ▪ Water demand<br>▪ Raw water quality | WD<br>WQ | EX |

| | | | | |
|---|---|---|---|---|
| 1952 | Construction of new reservoir | Remain sufficient pressure, despite growing demand | P | EX |
| 1976 | Shut down of production facility | ▪ Water quality issues<br>▪ Expanding of the city | WQ<br>3rd | EX |
| 1975 | Start-up of new facility | Replacing shut down facility (Water demand) | WQ<br>3rd<br>WD | EX |
| ± 1988<br>± 2010 | ▪ Expand treatment with UV-disinfection<br>▪ Removal of UV installation | ▪ Public health<br>▪ Groundwater pollution<br>▪ Improvement groundwater quality | 3rd<br>WQ | EX |
| 1940 – 1965 | ▪ Research extraction alternatives<br>▪ These alternatives showed insufficient capacity and quality | Desire to stay independent of provincial water company and to stay self-sufficient? | DEP<br>ORG<br>GEO | IN<br>EX |
| 1930 - 2000 | ▪ Research extraction alternatives | ▪ Extraction by other parties (water company, cement industry)<br>▪ Poor availability water on west side | 3rd<br>GEO | EX |
| 1978 | Construction of new facility | Capacity problems at other production site because of extraction by other water company | 3rd<br>WD | EX |
| 1999 - 2008 | Construction of softening plant and transport pipelines | Customer satisfaction | CUST | IN |
| ± 2000 | Lay-out of the centralized softening<br>▪ Connect De Tombe (municipality)<br>▪ Shut-down Dommel (WML)<br>▪ Shut-down Borgharen and Caberg (municipality) | ▪ Cooperation and merger<br>▪ Water supply plan<br>▪ Costs (clustering) | €<br>ORG<br>SUP<br>GEO | TR |
| 2000 | Shut-down The Dommel | ▪ Costs<br>▪ Water quality<br>▪ Alternatives available | €<br>WQ<br>SUP | IN |

| | | | | |
|---|---|---|---|---|
| 2008 | Shut-down Borgharen and Caberg (municipality) | ▪ Availability from other production facilities<br>▪ Water quality: hardness, risk of flooding, third party activities) | SUP<br>€<br>WQ<br>GEO<br>3rd | EX<br>IN |
| 1998 - present | Investing in cooperative program with farmers | ▪ Water quality<br>▪ Nitrate standard<br>▪ Agricultural activities | 3rd<br>POL<br>GEO<br>WQ | TR |
| 1999 – 2008 | *Occurrence rather than investment, but leading to a change of planned investments:*<br>Isolated systems become part of larger system. Water distribution plan is considered integrally, on a city-exceeding scale. This leads to adaptation of the drinking water infrastructure of the city. | Merger of isolated and autonomic municipalities to larger scale provincial companies | ORG<br>SUP/SEC<br>€ | IN |
| > 1960 | Break-down of reservoir | Activities of cement industry | 3rd | EX |
| ± 2010 | ▪ Expanding reservoir capacity<br>▪ Renovation of reservoirs and boosters | Security of supply and asset condition | SEC<br>RNV | IN |
| Entire period | Several different kinds of river crossing transport pipelines | ▪ Security of supply<br>▪ Major production on east side | SEC<br>GEO<br>AVB | EX |

## 8.5 Drivers for infrastructural developments Amsterdam

The following drivers can be identified from the historical developments of the infrastructure of the urban area of Amsterdam.

TABLE 6; DRIVERS HISTORICAL DEVELOPMENT DRINKING WATER INFRASTRUCTURE AMSTERDAM (DRIVER CODES REFER TO TABLE 2).

| Year | Investments or occurrence | Driver | Classification driver | Internal/ Trans/ External |
|---|---|---|---|---|
| | | | | |
| **Mostly LEIDUIN** | | | | |
| | | | | |
| 1853 | Start-up Leiduin site<br>Transport pipeline (23 km) | Transport water from production site to the city | SUP | IN |
| 1888 | Construction of the second treatment facility (WPK) | ▪ Water demand<br>▪ Water pressure<br>▪ Availability dune water | WD<br>P<br>AVB | EX |
| 1900 | Renewing and expanding facilities | ▪ Growth of city<br>▪ Water quality | WD<br>WQ | EX |
| Entire period | Many transport pipeline works. Also river, canal and lake crossings. | ▪ Water supply plan<br>▪ Security of supply | SEC<br>WD<br>SUP | EX |
| 1920 | ▪ Deeper extraction<br>▪ Construction of pre-filtration | ▪ Availability of shallow water<br>▪ Changed raw water quality | AVB<br>WQ | EX |
| 1920s-1930s | ▪ Expanding pre-filtration and slow sand filtration<br>▪ Expand pumping capacity raw water collection dunes | Increasing water demand | WD | EX |
| ± 1955 | Replace pre-filtration with rapid sand filtration | Improving water quality, adapt technology | TECH<br>WQ | IN |
| 1920s | ▪ Additional transport pipelines<br>▪ Additional booster station | ▪ City growth by annexation<br>▪ Low water pressure | WD<br>P | EX |
| 1929 –<br><br><br><br><br><br>1934 | ▪ *Occurrence:* Decision to adapt Weesperkarspel plant for drinking water purpose<br>▪ Research possibilities of alternative sources for Weesperkarspel<br>▪ Research possibility of dune infiltration<br>▪ Plan: artificial infiltration in dunes + expanding and improving Weesperkarspel | Growing water demand cannot be met with one production facility | WD<br>WQ<br>AVB | EX |

| | | | | |
|---|---|---|---|---|
| 1948 | ▪ Fourth transport pipeline between dunes and city.<br>▪ With several cross connections<br><br>▪ Material choice: concrete instead iron | ▪ Water demand<br>▪ Continuous water supply<br><br>▪ Scarcity of iron | WD<br>SEC<br><br><br>SCAR | EX<br><br><br><br>EX |
| 1953 | Expand storage capacity | ▪ Water demand<br>▪ Continuous water supply | WD<br>SEC | EX |
| 1950s | Covering of slow sand filters | ▪ Prevent freezing<br>▪ Prevent algae growth | WQ<br>GEO | EX |
| 1952<br><br>1954-1957 | Establishment of WRK (transport of river water to dunes)<br>Construction of WRK-I comprises:<br>▪ Pre-treatment facility<br>▪ Transport pipeline\ works | ▪ Growing water demand (household and industry)<br>▪ Limited amount of dune water<br>▪ Ability to rely on existing dune facilities / dependent on historical infrastructure | WD<br>AVB<br><br><br><br><br><br>€<br>HIST | TR<br><br><br><br><br><br><br>IN |
| 1952 | Choice of location of WRK | Objection of city of Utrecht on waste water disposal location | 3rd | EX |
| 1970s | Expand pre-treatment of WRK | Improvement of water quality | WQ<br>(OP/€) | IN |
| 1980s | Cease transport chlorination | Public health | WQ | IN |
| > 1960 | Back-up groundwater wells at WRK | Pollution of surface water | 3rd | EX |
| 1957 | Adapt dune facilities (construct infiltration works) | Change of system (new source) | TECH | IN |
| 1961 | ▪ Expanding dune water treatment facility<br>▪ Renewal | ▪ Growing water demand<br>▪ Security of supply<br>▪ Condition of assets | WD<br>RNV | EX<br>IN |
| 1960s | ▪ Powder carbon dosage installation<br>▪ Chlorine dosage installation | Source water quality<br>Meeting standards | WQ<br>POL | EX<br>IN |
| ± 1965 | Construction of WRK-II comprising:<br>▪ New transport pipelines<br>▪ Expanding of pre-treatment facilities | Growing water demand | WD | EX |
| Future | *Occurrence:*<br>New contract negotiations might have impact on exploitation of WRK | Contract expiration | CONTR<br>3rd | TR |

| | | | | |
|---|---|---|---|---|
| 1960s | ▪ New transport pipeline<br>▪ Construction booster station<br>▪ Expanding storage capacity<br>▪ Construction of additional storage facility | ▪ Improving transport capacity<br>▪ Water demand, limited capacity of existing works<br>▪ Balance pressure variations | SEC<br>WD<br>P | IN<br>EX |
| 1960s | Installing of 100.000 non-return valves | Prevent contamination of drinking water | WQ<br>3rd | IN |
| 1968 | Expanding of dune water treatment facilities | Water demand (tune capacity to capacity of pre-treatment) | WD | EX |
| 1968 | Fifth transport pipeline between dunes and city | ▪ Water demand<br>▪ Continuous water supply | WD<br>SEC | EX |
| 1980s | Renew raw water collection facility, keep former one as back-up | Asset condition | RNV | IN |
| 1994 | Renovation of distribution pumping station | Asset condition | RNV | IN |
| ± 1990 | Expand treatment plants with softening | ▪ Customer comfort, and later:<br>▪ Public health (water quality), energy, environment | CUST<br>WQ<br>E<br>ENV | IN |
| 1995 | ▪ Construction of ozonation<br>▪ Construction of activated carbon<br>▪ Weesperkarspel was adapted prior to Leiduin | ▪ Raw water quality changes (pollution)<br>▪ Improve treatment to newest technical standards<br>▪ Meet Decree and company-specific quality standards | WQ<br>TECH<br>POL<br>€<br>PLAN | IN<br>EX |
| ± 2012 | ▪ Renovation of ozonation, however:<br>▪ 4 of the 5 chambers are renovated, one is taken out of operation | ▪ Asset condition<br>▪ Stabilization of water demand | WD | EX |
| > 1960 | Repeated consideration for covering of raw water collection. No investment yet | ▪ Protection of reclaimed raw water quality<br>▪ Costs | WQ<br>€<br>HIST | |

| | | | | |
|---|---|---|---|---|
| | | ▪ Historical development of infrastructure | | |
| | | | | |
| **Mostly WEESPERKARSPEL** | | | | |
| | | | | |
| 1888 – 1930s | *Occurrence:*<br>Weesperkarspel water did not qualify for drinking water purpose.<br>Existence of two different water qualities<br><br>*Investment:*<br>Double distribution network system | ▪ Raw water quality (location, upstream disposal waste water, salt) and insufficient treatment<br>▪ Customers opinion | WQ (3rd, AVB, GEO)<br>TECH<br>CUST | EX |
| ± 1915 | Search for and switch to alternative source | Water quality (high salt content river Vecht) | WQ | EX |
| ± 1920<br><br><br><br>1920s | *Occurrence:*<br>Repeated switching between Vecht and Merwede source water<br><br>*Investment:*<br>Research possibilities for alternative sources | Source water quality | WQ<br><br><br><br>AVB | EX |
| 1928 | Acquire land for drinking water treating purposes | ▪ Search for alternative sources<br>▪ Signals for future activities of other parties | WQ<br>AVB<br>3rd | TR |
| 1930s | ▪ Adaptation of raw water collection<br>▪ Adaptation of water treatment | New raw water source | WQ | IN |
| 1939 | Vanishing of separate distribution networks | Improvement of Weesperkarspel water quality | WQ | IN |
| 1930s | ▪ Adaption of filtration process<br>▪ Increase treatment capacity<br>▪ Increase storage capacity | ▪ Improving water quality and operation<br>▪ Increasing water demand | WD<br>WQ<br>TECH | IN<br>EX |
| 1940s | *Occurrence:*<br>Switch back to alternative water source | Contamination of source water by invaders | 3rd<br>WQ | EX |
| 1941 | Increase of treatment capacity<br>Installation of disinfection unit | ▪ Increasing water demand<br>▪ Meet water | WD<br>WQ, POL | EX |

| | | | | |
|---|---|---|---|---|
| | | quality standards | | |
| 1950s | ▪ Construction of separated drinking water lake<br>▪ Construction of drinking water canal | ▪ Improvement of source water quality and pre-treatment<br>▪ Increasing pollution of surroundings | WQ<br>3rd | IN |
| 1950s | *Occurrence:*<br>▪ Colored water<br>▪ Algae growth<br>*Investment:*<br>▪ Research of ozone application<br>▪ Improvement of the hydrological properties of lake and canal<br>▪ Adaptation of pre-treatment (coagulation) | ▪ Source water quality<br>▪ Customer complaints on taste | WQ<br>GEO<br>OP<br>CUST | EX |
| 1950s-1960s | Research for alternative sources | Expected increase of water demand | WD | EX |
| >1960 | *Occurrence:*<br>Quality improvement of raw water | Waste water treatment | 3rd<br>POL | EX |
| 1977 | Rebuilt treatment facility and break-down of former facility.<br>New facility is expanded with ozonation, coagulation, optional dosing of powdered activated carbon.<br>Pre-treatment filters got covered. | ▪ Asset condition<br>▪ Improve drinking water quality water (customers, decree, public health)<br>▪ New technological insights<br>▪ Prevent freezing | RNV<br>WQ (CUST, POL)<br>TECH<br>GEO | EX |
| ± 1982 | ▪ Adaptation pre-treatment (separate coagulation step)<br>▪ Construction of alternative raw water intake | ▪ Improve lake water quality<br>▪ Alternative source for expected capacity increase | WQ<br>WD | IN |
| ± 1985 | Back-up intake Amsterdam-Rhine canal water | Availability | AVB | IN |
| 1983 | Stop post-chlorination | Public health (water quality) | WQ | IN |
| 1993 | Replace coagulation and sand filtration with activated carbon filtration | ▪ Raw water quality (pollution)<br>▪ New | WQ<br>TECH | EX |

| | | | | |
|---|---|---|---|---|
| | | technological insights | | |
| 1980s | Activated carbon filtration | Continuous improving of analyzing devices | TECH | TR |
| 1990s | Constant improvement of ozonation | ▪ Public health<br>▪ Water quality standards<br>▪ Microbiological contamination of source water | WQ<br>POL<br>GEO | EX |
| <1960 – 1990s | ▪ Redundant capacity pre-treatment filters<br>▪ Spatial planning and outline Weesperkarspel<br>▪ Environmental impact assessments<br>▪ Research of ultrafiltration applications<br>▪ Reservations for additional drinking water lake | Expected increase of water demand | WD | EX |
| | | | | |
| **Other investments** | | | | |
| | | | | |
| 1980s | ▪ Installation of activated carbon<br>▪ Shut-down groundwater production facility | ▪ Water quality (pollution)<br>▪ Small scale | WQ<br>3rd<br>€ | EX<br><br>IN |
| ± 2000 | Doubled piping systems | ▪ Public health (water quality)<br>▪ Government forced stopping of household water activities | WQ<br>POL | EX |
| >1960 | Reconstruct transport pipeline | Spatial development of airport | 3rd | EX |
| 1999 | Install water meters | Political decision? | POL | TR |
| | ▪ Reduce pressure in network<br>▪ Design of low pressure drop equipment | ▪ Save energy<br>▪ Increase asset lifespan | | |

## 8.6 Analysis of drivers

The objective of this study was to identify the most important developments of the drinking water infrastructure regarding the intake of source water, catchment areas and water wells, drinking water treatment, and transport, distribution and storage of drinking water by reviewing the historical developments and investments of the four Dutch urban areas of Amsterdam, Groningen, Arnhem-Nijmegen, and Maastricht. Although there are limitations to identify all the developments in one city, by reviewing the developments of several cities having various characteristics we believe the most relevant drivers could be identified.

### 8.6.1 Semi-quantitative analysis of drivers behind historical developments

The semi-quantitative analysis of the different drivers found includes approximately 225 investments that were identified in the period 1850 – 1914. This period was divided in sub periods in order to investigate possible occurrence of trends. Periods of interest are the entire period (prior to 1900 – 2014), the period prior to 1960 (< 1900 – 1960), and the period after 1960 (1960 – 2014). The last period is further subdivided into the period 1960 – 1985 and the period 1985 – 2014.

The results for the recurrence of drivers are presented in the tables below. Table 7 presents the absolute numbers of drivers identified. In this table, the “quarter icons” indicate the relative occurrence rates of the drivers:

| | |
|---|---|
| ○ | Lowest relative occurrence rate |
| ◔ | Low relative occurrence rate |
| ◑ | Medium relative occurrence rate |
| ◕ | High relative occurrence rate |
| ● | Highest relative occurrence rate |

Table 8 presents the relative occurrence rates of the drivers as a percentage.

TABLE 7; ABSOLUTE OCCURRENCE OF DRIVERS.

| Drivers | PERIOD < 1900 - 1960 | | | | | | | PERIOD 1960 - 1985 | | | | | | | PERIOD 1985 - 2014 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Amsterdam | Groningen | Maastricht | Nijmegen-Arnhem | Total Surfacewater | Total groundwater | Total | Amsterdam | Groningen | Maastricht | Nijmegen-Arnhem | Total Surfacewater | Total groundwater | Total | Amsterdam | Groningen | Maastricht | Nijmegen-Arnhem | Total Surfacewater | Total groundwater | Total |
| WQ = water quality | 16 | 4 | 6 | 2 | 20 | 8 | 28 | 6 | 7 | 4 | 4 | 13 | 8 | 21 | 8 | 9 | 4 | 5 | 17 | 9 | 26 |
| AVB = availability source water | 6 | 1 | 4 | 1 | 7 | 5 | 12 | 0 | 2 | 1 | 0 | 2 | 1 | 3 | 1 | 1 | 1 | 0 | 2 | 1 | 3 |
| WD = water demand | 10 | 1 | 7 | 5 | 11 | 12 | 23 | 8 | 4 | 3 | 3 | 12 | 6 | 18 | 3 | 4 | 0 | 3 | 7 | 3 | 10 |
| SEC = security of supply | 2 | 0 | 10 | 1 | 2 | 11 | 13 | 3 | 0 | 1 | 0 | 3 | 1 | 4 | 0 | 5 | 2 | 1 | 5 | 3 | 8 |
| P = pressure | 2 | 1 | 2 | 1 | 3 | 3 | 6 | 1 | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 1 | 0 | 2 | 1 | 2 | 3 |
| SUP = water supply plan | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 2 | 1 | 0 | 4 | 5 | 1 | 9 | 10 |
| GEO = geographical, climate | 2 | 0 | 5 | 4 | 2 | 9 | 11 | 1 | 1 | 2 | 0 | 2 | 2 | 4 | 1 | 2 | 5 | 1 | 3 | 6 | 9 |
| POL = governmental/provincial policy, decree | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 2 | 2 | 2 | 4 | 5 | 4 | 1 | 9 | 8 | 10 | 18 |
| 3rd = third party | 4 | 2 | 2 | 3 | 6 | 5 | 11 | 3 | 0 | 5 | 1 | 3 | 6 | 8 | 4 | 0 | 5 | 4 | 4 | 9 | 12 |
| TECH = technological development | 4 | 0 | 0 | 1 | 4 | 1 | 5 | 1 | 1 | 1 | 1 | 2 | 2 | 4 | 3 | 4 | 0 | 0 | 7 | 0 | 7 |
| CUST = customer | 2 | 1 | 1 | 0 | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 4 | 1 | 6 | 7 |
| SCAR = scarcity of materials | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| DEP = dependency of other parties | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| RNV = renovation (because of age) | 0 | 2 | 0 | 1 | 2 | 1 | 3 | 2 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | 1 | 1 | 3 | 3 | 4 | 7 |
| € = costs | 0 | 0 | 2 | 1 | 0 | 3 | 3 | 3 | 0 | 0 | 2 | 3 | 2 | 5 | 4 | 6 | 5 | 8 | 10 | 13 | 23 |
| PLAN = investment&project planning, timing | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| HIST = dependent of historical infrastructure | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 0 | 2 |
| CONTR = contracts | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| ORG = organizational | 0 | 1 | 1 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 4 | 1 | 6 | 7 |
| IMG = image | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 2 |
| OP = operations | 1 | 1 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E = Energy | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 1 | 2 | 3 |
| ENV = environment, sustainability | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 2 |
| **Total** | **51** | **14** | **41** | **21** | **65** | **62** | **127** | **29** | **16** | **18** | **15** | **45** | **33** | **77** | **37** | **41** | **32** | **52** | **78** | **84** | **161** |

## TABLE 8; RELATIVE OCCURRENCE OF DRIVERS.

| | PERIOD < 1900 - 1960 | | | | | | | PERIOD 1960 - 1985 | | | | | | | PERIOD 1985 - 2014 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drivers | Amsterdam | Groningen | Maastricht | Nijmegen-Arnhem | Total Surfacewater | Total groundwater | Total | Amsterdam | Groningen | Maastricht | Nijmegen-Arnhem | Total Surfacewater | Total groundwater | Total | Amsterdam | Groningen | Maastricht | Nijmegen-Arnhem | Total Surfacewater | Total groundwater | Total |
| WQ = water quality | 31% | 29% | 15% | 10% | 31% | 13% | 22% | 21% | 45% | 23% | 27% | 29% | 25% | 27% | 22% | 22% | 13% | 10% | 22% | 11% | 16% |
| AVB = availability source water | 12% | 7% | 10% | 5% | 11% | 8% | 9% | 0% | 13% | 6% | 0% | 4% | 3% | 4% | 3% | 2% | 3% | 0% | 3% | 1% | 2% |
| WD = water demand | 20% | 7% | 17% | 24% | 17% | 19% | 18% | 26% | 26% | 17% | 20% | 26% | 18% | 23% | 7% | 10% | 0% | 6% | 8% | 4% | 6% |
| SEC = security of supply | 4% | 0% | 24% | 5% | 3% | 18% | 10% | 10% | 0% | 6% | 0% | 7% | 3% | 5% | 0% | 12% | 6% | 2% | 6% | 4% | 5% |
| P = pressure | 4% | 7% | 5% | 5% | 5% | 5% | 5% | 3% | 0% | 0% | 7% | 2% | 3% | 3% | 0% | 2% | 0% | 4% | 1% | 2% | 2% |
| SUP = water supply plan | 0% | 0% | 0% | 5% | 0% | 2% | 1% | 3% | 0% | 0% | 7% | 2% | 3% | 3% | 3% | 0% | 13% | 10% | 1% | 11% | 6% |
| GEO = geographical, climate | 4% | 0% | 12% | 19% | 3% | 15% | 9% | 3% | 6% | 11% | 0% | 4% | 6% | 5% | 3% | 5% | 16% | 2% | 4% | 7% | 6% |
| POL = governmental/provincial policy, decree | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 5% | 3% | 0% | 13% | 4% | 6% | 5% | 12% | 9% | 3% | 17% | 10% | 12% | 11% |
| 3rd = third party | 8% | 14% | 5% | 14% | 9% | 8% | 9% | 9% | 0% | 26% | 7% | 6% | 17% | 10% | 9% | 0% | 14% | 8% | 5% | 10% | 7% |
| TECH = technological development | 8% | 0% | 0% | 5% | 6% | 2% | 4% | 3% | 6% | 6% | 7% | 4% | 6% | 5% | 8% | 10% | 0% | 0% | 9% | 0% | 4% |
| CUST = customer | 4% | 7% | 2% | 0% | 5% | 2% | 3% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 3% | 0% | 6% | 8% | 1% | 7% | 4% |
| SCAR = scarcity of materials | 2% | 0% | 0% | 0% | 2% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| DEP = dependency of other parties | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 6% | 0% | 0% | 3% | 1% | 0% | 0% | 0% | 2% | 0% | 1% | 1% |
| RNV = renovation (because of age) | 0% | 14% | 0% | 5% | 3% | 2% | 2% | 7% | 0% | 0% | 0% | 4% | 0% | 3% | 5% | 2% | 3% | 6% | 4% | 5% | 4% |
| € = costs | 0% | 0% | 5% | 5% | 0% | 5% | 2% | 9% | 0% | 0% | 13% | 6% | 6% | 6% | 9% | 15% | 16% | 15% | 12% | 16% | 14% |
| PLAN = investment&project planning, timing | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 3% | 0% | 0% | 0% | 1% | 0% | 1% |
| HIST = dependent of historical infrastructure | 2% | 0% | 0% | 0% | 2% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 3% | 2% | 0% | 0% | 3% | 0% | 1% |
| CONTR = contracts | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 3% | 0% | 0% | 0% | 1% | 0% | 1% |
| ORG = organizational | 0% | 7% | 2% | 0% | 2% | 2% | 2% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 2% | 6% | 8% | 1% | 7% | 4% |
| IMG = image | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 5% | 0% | 0% | 3% | 0% | 1% |
| OP = operations | 2% | 7% | 0% | 0% | 3% | 0% | 2% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| E = Energy | 0% | 0% | 2% | 0% | 0% | 2% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 3% | 0% | 0% | 4% | 1% | 2% | 2% |
| ENV = environment, sustainability | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 5% | 0% | 0% | 0% | 3% | 0% | 1% |

The following general observations are found from this semi-quantitative analysis of drivers:

- The incentives for the 225 identified investments were classified by 23 types of drivers. The majority of these driver-types are found to occur throughout the entire period of concern, that is the 19th century until present time.

- The drivers ‘water quality’ and ‘water demand’ (plus security of supply) are the most frequently found drivers. This holds for all four cities, and for both the period prior to 1960 as well as the period after 1960.
- The drivers ‘third party’, ‘costs’, ‘geographical factors’, and ‘policy’ are the second most frequent found drivers.
- Some drivers, such as ‘scarcity’, ‘planning of investment’, ‘contracts’, ‘image’ and ‘operations’ only occur one or two times.

In order to further describe the historical variation of the occurrence of drivers, the analysis of the occurrence of drivers was performed in more detail for the different periods.

Comparison period before 1960 and period after 1960. Remarkable differences found between the period prior to 1960 and the period after 1960 (based on the absolute number of investments):

- The number of investments driven by the availability of sources seem to be smaller in the period after 1960, either because the companies have found a source suitable for drinking water purpose for which they do not need to search for different sources anymore, or companies are adapting the treatment process to deal with changing water quality of the source.
- Almost all investments because of changing water supply plans occur in the later period. Most likely because the large mergers between the municipality and the provincial companies (leading to more integral supply plans) occur in this period.[3]
- All investments due to policy-regarded reasons occur in the period after 1960.
- The number of investments due to third parties are higher for the period after 1960.
- Almost all decisions (to invest, to not invest, to adapt) driven by costs were found to be in the period after 1960.
- Due to the mergers and acquisitions in the second period, the number of investments driven by organizational changes show an increase.
- Although the absolute number of reported investments driven by sustainability (environment, energy) are small, these investments show an increase in time.

- Additionally, the next difference is found between the period prior to 1960 and the period after 1960, based on the relative occurrence (rather than the absolute number) of drivers:The relative occurrence of ‘water demand’ driven investments decreases for all cities except for Groningen.

Comparison period 1960-1985 and period after 1985. The driver overview does hardly seem to be suitable for detection of trends within the period of 1960 till present, mostly because of the relative small amount of data per driver. However, when the period after 1960 is cut in two sub periods (1960-1985 and 1985-2014), the following observations are made, based on the absolute number of investments:

[3] In this case, the actual driver is ‘organisation’ rather than ‘water supply plan’. In this study, the analysis does not account for such underlying or “root” drivers.

- For Amsterdam and Maastricht, the number of investments because of water demand seem to be smaller for the period between 1985 – 2014 compared to the period between 1960 – 1985. This is in agreement with the trend of the decreasing water demand[4] since the 1990s.
- There is an increase in investments because of the water supply plan, for Maastricht and Nijmegen-Arnhem, because these urban water infrastructures became part of a larger scale infrastructure due to mergers.
- The majority of investments because of policy-regarded reasons occur in the period after 1985. A partial explanation is the policy for the protection of dry-out of soil which was introduced in this period.
- There is an increase in investments driven by customers, mostly because of the construction of softening plants.
- The number of renovation driven investments increases. This is due to the fact that most of the expansion driven investments were done until the 1980s – 1990s (related to the development of the water demand), and the replacement investments (e.g. renovation) is lagging these expansion investments.
- Almost all decisions (to invest, to not invest, to adapt) driven by costs were found to be in the period after 1985.
- Due to the mergers and acquisitions in the period after 1985, the number of investments driven by organizational changes show an increase.

- Additionally, the following observation is made, based on the relative occurrence (rather than the absolute number) of drivers, for comparison of the periods 1960-1985 and 1985-2014:
  The relative occurrences of the drivers ‘water quality’ and ‘water demand’ is decreasing in time. There is a shift from high relative occurrences of these drivers to other drivers such as ‘policy’, ‘costs’, ‘organization’, ‘water supply plan’, and sustainability.

### 8.6.2 Moving targets in dynamic systems

In this case, the unit of study is the urban water infrastructure and this unit is a dynamic system with moving targets. The moving targets refer to the changing needs and expectations of different stakeholders over time. The driver overview has not accounted for the relative importance (‘weight’) of drivers, because the weight of the different drivers also changes over time, and probably also per location. The investment costs (the ‘weight’ of the investment) could be regarded as an impact factor, however this factor is not included in the driver overview because of lack of data.

Hence, the system develops over time, the targets will change, and as a consequence the weight of investments and drivers is subject to change as well. For instance, in the first decades it was quite common that parts of the city could not be provided with water for short periods and during these times the focus was to increase connectivity, production capacity and water pressure. Later, when the connectivity reached 100%, it became more important to further increase security of supply. A similar observation holds for the development of the number and the values of water quality standards. A third example is the introduction of sustainability as a driver for investments which only appears in the final decades.

### 8.6.3 The rate of change of driver-occurrence

Based on the analysis of the trends of the occurrence of drivers, it can be suggested that it is required to analyse a large period of time to identify such trends. We based the trends on

[4] Agudelo-Vera, C.M., Büscher, C., Palmen, L., Leunk, I., Blokker, E.J.M. *Transitions in the drinking water infrastructure – a retrospective analysis from source to tap,* 2015.

the data of three periods of at least 25 years (paragraph 8.6.1), and it is suggested to at least analyse a period of halve a century to identify trends or differences in the occurrence of drivers.

### 8.6.4 The rate of change of systems: inertia and flexibility

Based on the analysis of the infrastructural developments, on the one hand the inertia (or path dependency) of the drinking water infrastructure is confirmed. But on the other hand the historical analysis shows that the system is flexible, meaning that the system can be adapted to cope with changing conditions over decades.

Drinking water systems have large inertia, due to large investments and long life times. For instance, the sites of the surface water treatment plants of Amsterdam and Groningen have been at the same location ever since the first establishment. However, the drinking water treatment infrastructure is flexible in many aspects, for instance, to cope with changes in the source of the water. The treatment has been adapted and upgraded several times due to changes of the source water quality or in order to meet more stringent drinking water standards. Another example is the transport pipeline system, which connects the treatment plant to the cities. This network was gradually expanded to meet the growing water demand and guarantee a secure water supply. The basic outline of the transport pipeline system is rather constant because of the steady situation regarding the location of the treatment plants and the cities.

Although the incremental changes offer possibilities to transition to new system configurations, these additional investments reinforce the inertia of the system. The large scale infrastructural sites (with sunk costs), stimulates the continuous development, adaptation and improvement of these sites rather than the development of new sites, because of costs and because of spatial planning.

Many of the production facilities of the cities of Arnhem, Nijmegen an Maastricht have always existed since the establishment. As opposed to Nijmegen and Arnhem, the municipality of Maastricht had to search for new groundwater extraction sites several times since groundwater was more abundant in the Nijmegen-Arnhem area. The groundwater extractions of Maastricht and Nijmegen that were situated within the urban area (or even in the city center) have been abandoned or will be abandoned in the near future. As opposed to the location of the surface water treatment plants of Amsterdam and Groningen, many groundwater extraction sites near Maastricht, Arnhem and Nijmegen were abandoned.

Although most of the facilities built in the 19th century or the beginning of the 20th century are still in use, they have undergone several adaptations. The review shows the diversity of the arrangements to supply water and the flexibility of these systems reflected on the possibility to switch sources, treatments, organizational management (private or public) and anticipate on varying demands. Production facilities have shown to be flexible to a certain extent allowing changes of sources within time spans of a decade, which shows the adaptability of the system. During the time span of a century we see important changes in managerial issues, such as changing from private to public ownership, and mergers. Additionally, we see that technological developments had an influence on adaptation of the treatment facilities.

The inertia on the one hand and the occurrence of many adaptations and modifications on the other hand is illustrated in Figure 12 and Figure 13 for the case of Amsterdam and Maastricht. The overview shows the existence (start-up and shut-down) of abstraction and treatment facilities over time, as well as the most important identified modification moments.

The most important investment moments are taken from Table 5 and Table 6, and are classified as follows:

| Investment | Abbreviation | Symbol |
|---|---|---|
| Start-up | S |  |
| Shut-down | E |  |
| Expanding capacity | C |  |
| Renovation | R |  |
| Water quality | Q |  |
| Unspecified | X |  |

FIGURE 12; OVERVIEW OF MOST IMPORTANT CHANGES IN THE INFRASTRUCTURAL DRINKING WATER SYSTEM OF URBAN AREA OF AMSTERDAM (TAKEN FROM TABLE 6).

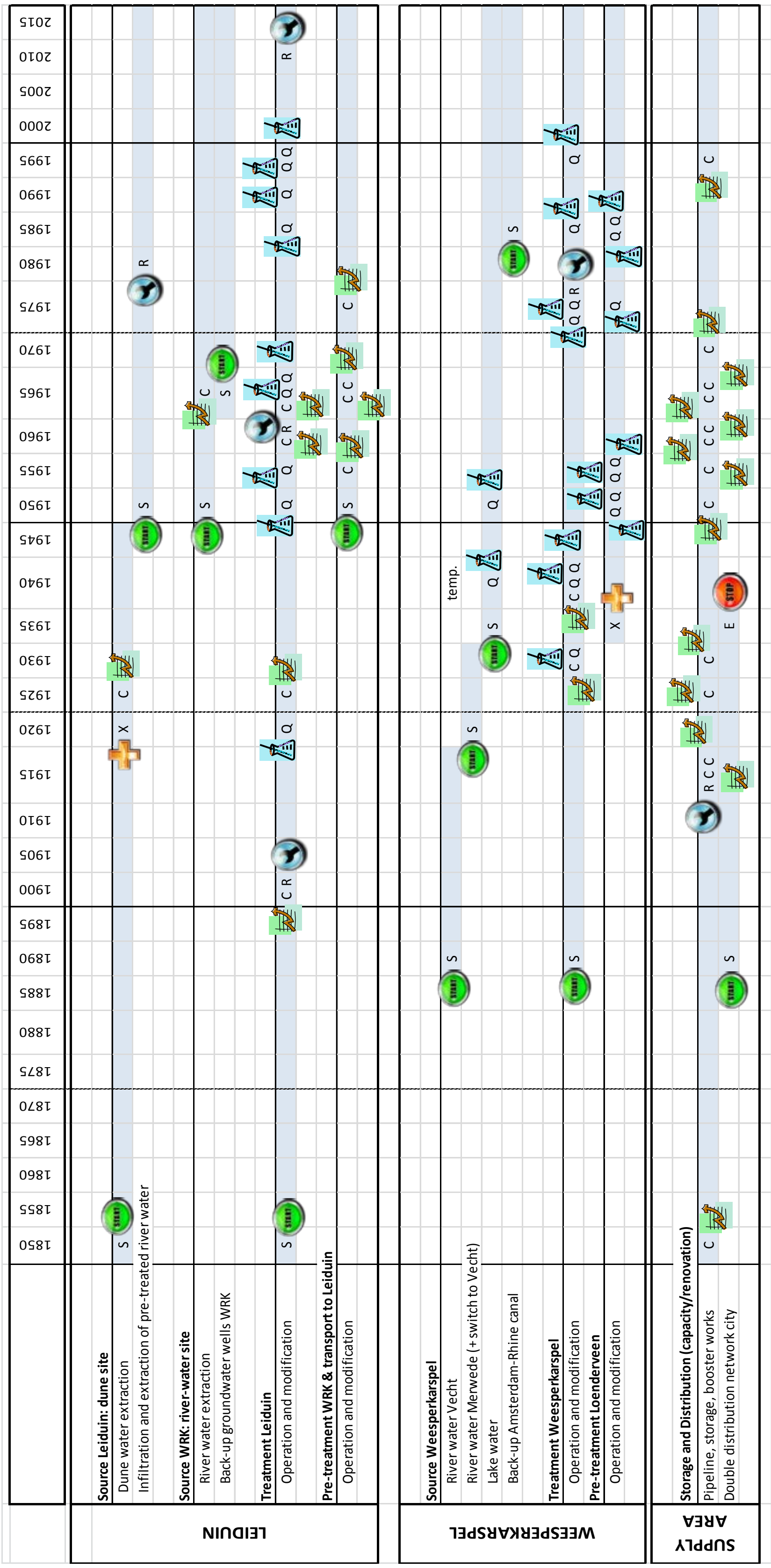
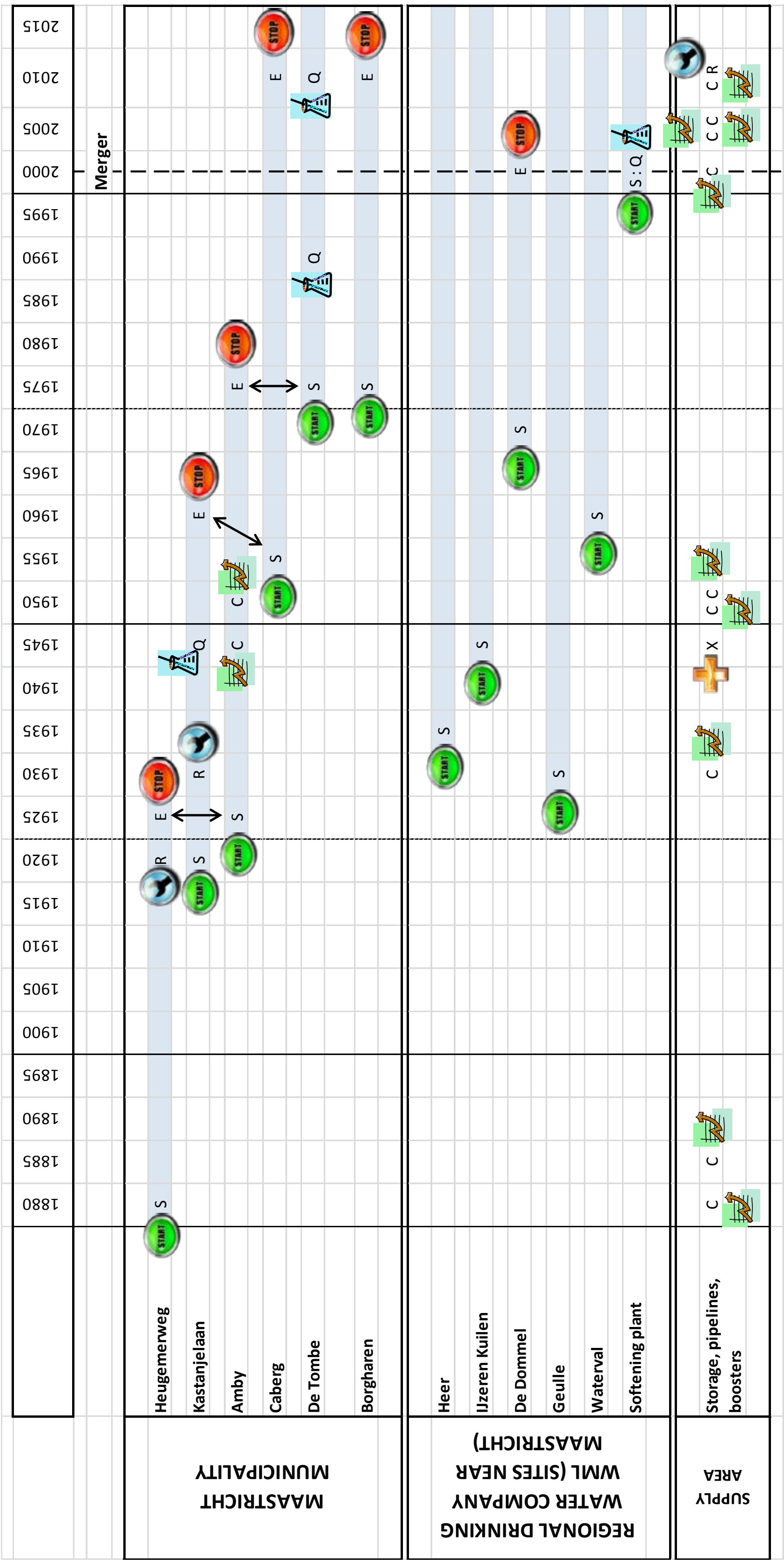


FIGURE 13; OVERVIEW OF MOST IMPORTANT CHANGES IN THE INFRASTRUCTURAL DRINKING WATER SYSTEM OF URBAN AREA OF MAASTRICHT (TAKEN FROM TABLE 5).



The identified investments are presented in a cumulative way over time for all four cities in Figure 14. The cumulative rate includes all identified investments in the source, abstraction, (pre)treatment, transport, distribution and storage assets. These assets together define the infrastructural drinking water system as a whole.

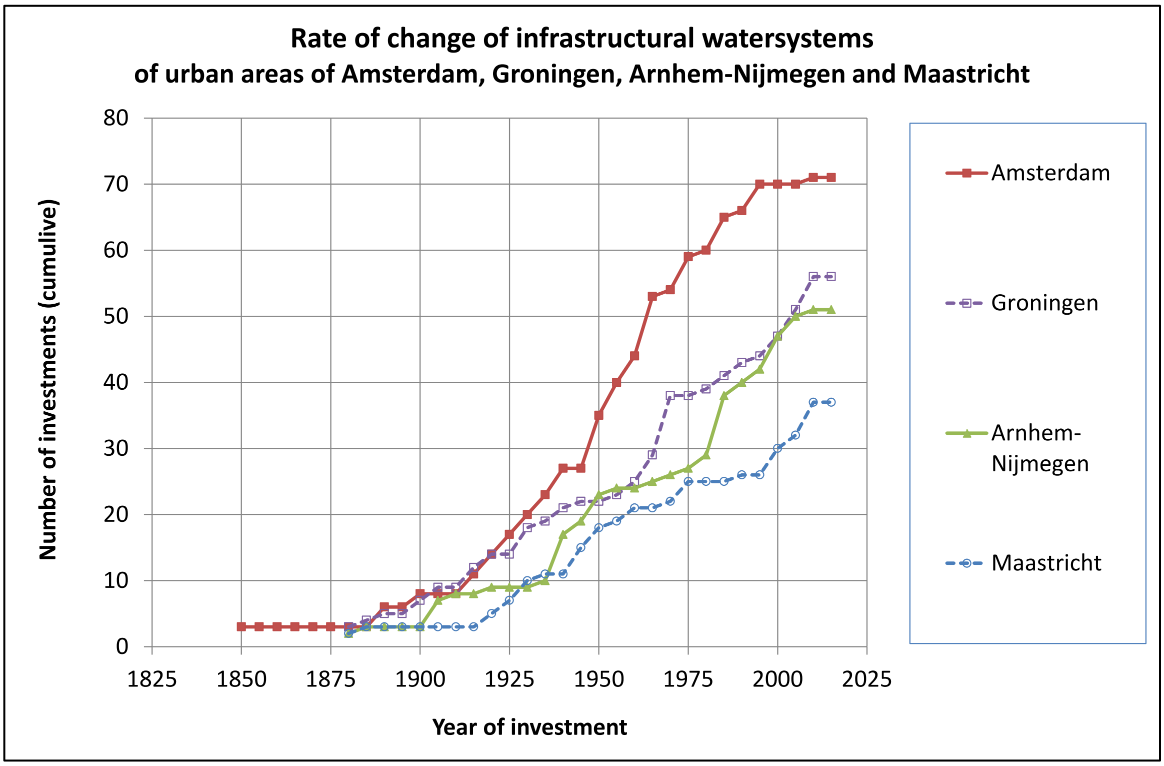



FIGURE 14; RATE OF CHANGE OF INFRASTRUCTURAL DRINKING WATER SYSTEMS OF THE URBAN AREAS OF AMSTERDAM, GRONINGEN, ARNHEM-NIJMEGEN AND MAASTRICHT INDICATED BY THE CUMULATED NUMBER OF INVESTMENTS / OCCURENCES (MOST IMPORTANT INVESTMENTS TAKEN FROM TABLE 3 - TABLE 6.

Figure 12 - Figure 14 indicate that a time span of several decennia is required in order to identify transitions of infrastructural drinking water systems. This suggested time span holds for the identification of trends within large scale infrastructural systems (in this case the drinking water system), which are defined by the whole of smaller sub-systems (e.g. subtraction, treatment, transportation), which on their turn are built from smaller units (e.g. filter-units or pipeline segments). Hence, a large time span is needed to describe transitions in an integral infrastructural drinking water system, whereas shorter time spans suffice to identify changes at sub-system or asset-unit level, e.g. as shown in Agudelo-Vera et. al., 2015)[5].

### 8.6.5 Generic drivers and local implications

Over the period of study, different changes in the SEPTED dimensions have had an influence on the drinking water infrastructure. Water quantity (source availability and/or demand), water quality and security of supply are examples of identified generic drivers, shaping the landscape, which are common for all different analysed locations and are driving changes in the system over the analysed period of time.

[5] Agudelo-Vera, C.M., Büscher, C., Palmen, L., Leunk, I., Blokker, E.J.M. *Transitions in the drinking water infrastructure – a retrospective analysis from source to tap,* 2015.

But the presence of such generic drivers at all locations may have different effects on the cities. Besides, although general landscape drivers and pressures are common for the four cities (e.g. national policy, economic development, war), the review shows that the development of drinking water infrastructure is strongly influence by the local factors. For instance, the surface water treatment facilities of Amsterdam and Groningen have shown a continuous adaptation and improving since the establishment, whereas the groundwater production facilities of Arnhem, Nijmegen and Maastricht supplied its water without or with very limited treatment until the 1980s. The majority of the current treatment processes installed at these groundwater facilities were constructed after 1985. Groningen and Amsterdam had to anticipate on the changing source water quality and they constantly strived for improvement of the drinking water quality. Again, it is important to emphasize that the customer’s needs and perceptions, the regulations and the systems requirements also change over time.

The drinking water infrastructure is strongly linked to the water source. Amsterdam, Groningen and Maastricht have put many efforts in the search for new, supplementing or more suitable water sources. The raw water extraction system and the surface water treatment plants of Amsterdam and Groningen were adapted to the changing raw water quality. Several groundwater facilities of Maastricht were shut down, but only after new groundwater extraction sites were found. For many decades, the cities of Arnhem en Nijmegen were served with water from the same four production facilities, and only recently one of them was shut down.

Remarkable differences found between surface water and groundwater companies, with respect to driver occurrence (taken from Table 7and Table 8):

- Larger amount of investments driven by third parties for the groundwater companies.
- Larger amount of investments driven by changing water supply plans for the groundwater companies. This could be explained by the fact that the water supply plan of Maastricht and Arnhem-Nijmegen was changed because of the merger with the provincial company.
- Larger amount of investments driven by technology for the surface water companies. This could be explained by the fact that surface water needs more sophisticated treatment.

Remarkable differences found between the four cities, with respect to driver occurrence:

- Groningen has little investments because of third parties in comparison to the other three cities.
- Amsterdam is the only municipal water company left in The Netherlands. The drinking water infrastructure of this city seems less affected by the development of the nearby provincial companies. The municipality did not need to merge with other drinking water companies because of its size, for which no organizational driver was found for investments.

## 8.7 Analysis of span of influence

In addition to the classification of the drivers, the reasons for investment were classified as ‘internal’, ‘transactional’ and ‘external’, referring to the amount of influence the company has on the decision to invest.

### 8.7.1 Semi-quantitative analysis

Table 9 shows the relative occurrence of external, transactional and internal drivers for three periods: the period prior to 1960, the period between 1960 and 1985, and the period between 1985 and 2014.

TABLE 9; SPAN OF INFLUENCE.

| | < 1900 - 1960 | | 1960 - 1985 | | 1985 - 2014 | |
|---|---|---|---|---|---|---|
| **Amsterdam** | EX | 66% | EX | 66% | EX | 37% |
| | TR | 6% | TR | 0% | TR | 17% |
| | IN | 28% | IN | 34% | IN | 46% |
| | < 1900 - 1960 | | 1960 - 1985 | | 1985 - 2014 | |
| **Groningen** | EX | 44% | EX | 21% | EX | 17% |
| | TR | 22% | TR | 29% | TR | 28% |
| | IN | 33% | IN | 50% | IN | 56% |
| | < 1900 - 1960 | | 1960 - 1985 | | 1985 - 2014 | |
| **Maastricht** | EX | 62% | EX | 71% | EX | 26% |
| | TR | 4% | TR | 0% | TR | 21% |
| | IN | 34% | IN | 29% | IN | 53% |
| | < 1900 - 1960 | | 1960 - 1985 | | 1985 - 2014 | |
| **Nijmegen-Arnhem** | EX | 60% | EX | 37% | EX | 21% |
| | TR | 6% | TR | 21% | TR | 31% |
| | IN | 34% | IN | 42% | IN | 48% |

The following is observed:

- The relative occurrence of external drivers for investments seem to decrease over time for all four urban areas.
- The relative occurrence of internal and transactional drivers for investments seem to increase over time for all four urban areas.
- The relative occurrence of external drivers is the largest for the first period for all four cities. The large number of investments in capacity extension due to growing water demand up to the second halve of the 20th century is one of the explanations.
- The relative occurrence of internal drivers is the largest for the last period for all four cities. This increase could be explained by the increase of the number of adaptations and renovations of existing facilities and the adaptation of the outline of existing distribution systems e.g. due to mergers.
- In most cases (periods and cities), the relative occurrence of transactional drivers is smaller than the occurrence of external and internal drivers, although the occurrence of transactional processes seem to increase over time.

It does not seem possible to fully explain the shifts over time between the ratios of internal, transactional and external drivers for the different cities, because 23 interacting drivers are involved, local factors play a role and perspectives and requirements change over time. Perhaps, the drinking water companies have gained controllability (decrease of occurrence of external drivers) because of improved measurement methods, increased system robustness, or better forecasting. It is important for water companies to identify the transactional sphere, since this sphere contains possibilities to influence or steer transitions.

### 8.7.2 Managing socio-technical systems

Drinking water systems as socio-technical systems are subject to different external and internal forces as discussed earlier. Additionally, drinking water systems are managed by social actors and embedded in a "social regime". For the specific case of drinking water infrastructure, the system has to be managed to comply with (national) legislation, and it has to be integrated in local and regional developments. Lack of cooperation between the different levels of organization can impact the system.

For instance, in Groningen, Arnhem, Nijmegen and Maastricht it was shown that the municipal drinking water company got isolated by the growth of the provincial water company. After the merger of isolated and autonomic municipalities to larger scale provincial companies, it was found that the isolated systems became part of larger system and the water supply plans were considered more integrally, on a city-exceeding scale. This has led to the adaptation of the drinking water infrastructure of these cities, although the changes for Groningen are rather limited because of the pressure differences between the city zone and the provincial zone.

## 8.8 Input for future infrastructural developments

In most occasions, locations of water extraction and drinking water treatment remained the same for more than one century. The capacity of water extraction sites, treatment facilities, and transport-, distribution and storage facilities have gradually expanded throughout the years. In many cases, the drinking water treatment was gradually expanded with additional or adapted treatment. The overall development of the drinking water infrastructure can be characterized as incremental (evolution) rather than radical (revolution).

The historical development of four urban areas covering a period longer than one century revealed 23 different drivers for investments. From a semi-quantitative driver analyses, it was concluded that some drivers recur throughout the entire period. The occurrence of other drivers decreased whereas the occurrence of some divers increased over time. These drivers played a role in the past and in many occasions they still drive investments and developments nowadays. It is likely to presume that the drivers will play a role in the development of the future drinking water infrastructure. The existence of these drivers and the trends of their occurrence can be used to assess the consistency with future drinking water infrastructure scenarios.

The analysis of the span of influence of drinking water companies on the investments done generally show a decrease of the externally driven investments, and the transactional and internally driven investments seem to increase. A major part of this shift is caused by the stabilization of the water demand. Perhaps the increased scale of drinking water companies has had an influence on this shift as well. It is unknown to what extent drinking water companies were in control of this shift.

It is recommended to include the following observations in the research of future drinking water infrastructure scenarios:

- The development of the drinking water infrastructure has adapted in a gradual (incremental), rather slow, and continuous way. It is most likely that the incremental way of developing will continue.
- The development of drinking water infrastructure is influenced by many different drivers. This research identified 23 different types of drivers, and the majority of the drivers was found to play a role throughout the entire period of study (more than one century). The most frequent found drivers are: water quality, water demand, security of supply, third party, costs, geographical factors and policy. It is likely that these drivers will play a role in the future development of drinking water infrastructures. These drivers might be of influence in future transitions and may be of use in drinking water infrastructure forecasting programs. However, it is likely that some drivers of importance were not yet revealed in this research, and that new drivers can play a role in the future.

- In many occasions, it was found that investments were driven by multiple drivers. Most probably, this will hold for future investments as well.
- Investments were driven by external, transactional and internal processes, which will be the case in the future as well. The analysis showed a shift from external towards transactionally and internally driven investments.

## 8.9 Limitations and recommendations for further research

In order to provide the growing cities with drinking water, and to comply with the regulations concerning the connecting of household to the water mains, many investments comprised the expanding of tertiary distribution network system (water mains) in the cities up to the mid of the 20th century. Naturally, these investments were of great importance to the drinking water companies, however these investments were not included in this research.

During this research, the following developments appeared in the literature research and interviews as well. These developments were not included in this research in order to focus on the primary drinking water infrastructure. These cases might be of interest for future research.

- Process automation and ICT
- Energy and utilities (coal, gas, electricity, diesel, emergency power units)
- Design of distribution network (sectioning, reliability of supply, self-cleaning networks)
- Material choice in drinking water distribution
- The influence of the geological situation on source water quality developments
- Investments in securing the drinking water infrastructure after the 9/11 attacks.
- The investment in and forced governmental stop of fluoride dosing to drinking water

There are also drivers known to have led to investments which have not appeared in the literature review or interviews. An example is the BEEL (Beoordeling Externe Effecten Leidingen) method, used for the assessment of pipelines imposing risks to critical third party's assets in case of pipeline failure.

The quantitative driver analysis can be improved by including the entire historical investment portfolio of drinking water companies. The analyses could be enriched by weighting the investments based on the total investment costs or an alternative scale of importance. Furthermore, the analysis can be enriched by weighting drivers in case an investment is driven by more than one driver. It must be kept in mind that the weights can be time and location dependent.

# 9 General conclusions

Although most of the facilities built in the beginning of the 20th century are still in use, they have undergone a significant amount of major adaptations. The identified investments show the diversity of arrangements to supply water. The flexibility of these systems is reflected on the possibility to switch sources, adapt treatments, change organisation structures (private to public) and changing water demand. Production facilities have shown to be flexible to a certain extent, e.g. by allowing changes of sources within the time span of a decade, which shows the adaptability of the system. During the time span of a century we see important changes in managerial issues, such us changing from private to public ownership. Additionally, we see that although technological developments had a big influence on adaptation of the treatment facilities, different drivers at different times cause changes in the drinking water system.

The incentives for the 225 identified investments in the drinking water systems of four Dutch cities could be classified into 23 different drivers. The drivers 'water quality' and 'water demand' are the most frequent occurring drivers. Investments because of third parties, geographical factors, costs, and policy are of secondary interest. Some drivers, such as 'image' and 'sustainability', were only identified one or two times. In many cases, an investment was done because of multiple drivers. Most of the drivers found are recurring throughout the entire period, although some trends were found in the occurrence of drivers. Important trends are the search for suitable drinking water sources and the increasing customer connectivity and water demand in the early decades, and the investments induced by the merger of municipalities with larger scale systems. The driver overview did not account for the relative importance ('weight') of the drivers since the importance of drivers is subject to change in time, as is the infrastructural system, and the importance of drivers might be location dependent. Also, despite the presence of common generic drivers for all four cities, its effects on the development of the infrastructure of these cities are influenced by local factors.

The large inertia of drinking water systems – or path dependency – is confirmed, caused by large investments and long life times. However, it is also shown that the system is flexible, meaning that the system can be adapted to cope with changing conditions over the decades. During the time span of a century, several important changes are observed, such as managerial issues regarding company ownership and mergers, continuous capacity expanding to meet the growing water demand and frequent adjusting to changing water quality demands. Larger scale infrastructural sites (with sunk costs) are likely to stimulate continuous development (expanding, modification and renovation) rather than developing new sites. It is suggested that it is required to analyse a large period of time to describe transitions of drinking water infrastructure systems. Trends are based on the data of three periods of at least 25 years, and it is suggested to at least analyse a period of halve a century to identify trends or differences in the occurrence of drivers as well as to identify transitions in integral infrastructural drinking water systems.

The analysis of the sphere of influence of drinking water companies shows that the majority of the investments is driven by external factors in the early decades, mostly because the growing water demand drove the increase of the connectivity and the capacity expanding. In the later decades, many of the investments are internally driven, mainly because water companies can decide whether or not facilities need renovation or further improvement. In most cases (periods and cities), the relative occurrence of transactional drivers is smaller than the occurrence of external and internal drivers, although the occurrence of transactional processes seem to increase over time. It is important for water companies to identify and explore their transactional sphere of influence, since it contains possibilities to influence or steer transitions.