Future drinking water infrastructure: building blocks for drinking water companies for their strategic planning

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Contents

1 Past, present & futures of drinking water infrastructure: towards a guiding framework

Drinking water is and will remain a topic of high priority on the international and national political agendas. A critical element of this agenda comprises the infrastructure required to extract, produce and distribute water. This study deals with drinking water infrastructure in the Netherlands that although highly advanced, faces some major challenges. Major parts of the infrastructure are in need of maintenance, replacement, expansion and/or adaptation to changes and such works are likely to take place in the (near) future. Surely, these do not take place all at the same time, at the same place. But it will require huge amounts of resources, financial or otherwise and, moreover, typically involves investments for the (very) long term. Those responsible for these investments will want to know how best to plan for and carry out such works. The aim of this book is to support in this task, by providing a framework that will help practitioners in their strategic planning of drinking water infrastructure investments. This introductory chapter provides the foci and main assumptions underpinning the chapters and findings in this book, and introduces the overarching framework, its elements and what the reader can expect in this book.

1.1 Focus, main assumptions, outputs & outcomes

Firstly, the focus in this framework is on planning for and adapting to socio-technical change of drinking water infrastructure. This assumes that any strategic planning of drinking water infrastructure needs to consider both the social and technical aspects in relation to each other, not in isolation. Drinking water infrastructure comprises physical elements like pipes and pumps, but they are designed, implemented and operated by people (often through IT systems as intermediaries). Furthermore, all this occurs in a broader (urban) environment that influences (facilitates and hampers) the design, implementation and use of drinking water infrastructure. While the engineer might look for technologically optimal 'solutions', but often loses sight of who is to operate this technology or trends in behavior, the strategist might come up with the brightest ideas and concepts without taking into account the technical limitations. This book thus proposes that from the start of a strategic process, the two (and other professions) work closely together. This might seem like an open door. The research project where this book is based upon, however, has shown it is not; technical and social/ strategic departments and professionals still work very much in isolation.

Secondly, strategic planning of drinking water infrastructure requires investigating as well as combining socio-technical insights of the past and present with visions of the future. Physical drinking water infrastructure typically has a long-term lifespan; many of its parts in the Netherlands have been designed and implemented long ago, in a society with different values than those of today, with less urbanized landscapes, with less advanced (technological) knowledge and so forth. Hence, knowing how particular drinking water infrastructure systems have developed over time and how they have shaped its present state, is imperative for transitions to desired future states of such systems. This does not mean that alternative infrastructure systems cannot be visualized or planned for; on the contrary, this book argues that strategic planners do well to contemplate alternative futures and how their desired water infrastructure systems hold under such futures. Best, however, is to do this knowing how infrastructures have historically been shaped. The framework presented in this book provides examples of and building blocks for how to integrate socio-technical elements of past, present and (possible) futures.

Following from this, thirdly, the fact that strategic planning processes necessarily deal with the future, requires some comments on what 'the future' is and how it can be explored. In brief, when this book speaks of the future*s*, it actually means future*s*. The future, after all, is essentially unknown, but we can forecast and imagine short- and longer term futures and anticipate such futures by defining visions and actions to realize those visions (Segrave, 2014). The future is, moreover, both 'open' and 'closed'; past structures and agencies have created conditions that partly shape present and future ones, but there is also space to 'innovate' and do things differently, in the sense of reassembling existing things and processes in ways that are considered 'new'. And, as our actions today have implications for people, nature, etc. in the future, it is the task of strategic planners to assess what might be potential future consequences of the actions we intend to take now and take responsibility for those. For instance, certain strategic actions may be deemed unethical by strategic planners, or from the perspective of stakeholders such as citizens, in that they are likely to do harm to people/nature in the future, and hence, not be taken up in an organization's strategy. This is all the more important for drinking water infrastructure, given its (average) long-term lifespan[1].

What can the reader expect to find and what are limitations of the findings in this book? Here, it is useful to distinguish between *outputs* and *outcomes*. The book essentially provides strategic planners in the Dutch drinking water sector with three types of *output.* One is a framework providing guiding principles for the strategic planning of drinking water infrastructure. Readers can use this framework as starting point for *designing* the strategic planning process for water infrastructure. A second output comprises more concrete 'building blocks', 'tools' and specific insights strategic planners can use *during* this process, including methodologies, external future scenarios and drivers that characterize certain transitions in Dutch water infrastructure. A third output are research questions that emerged during the project underpinning this book, which provide fruitful directions for research agendas on drinking water infrastructure. Outputs differ from outcomes in terms of the 'value-added'; the outputs in this book are generic and must in strategic processes be adapted and made specific for companies' unique contexts and needs. Therein, too, lies its main limitation: those readers expecting to find what the future holds in store for them, for instance in terms of the most innovative, new drinking water technologies or ready-made chunks to be immediately applied, will not be served by this book. Rather, it offers a way of seeing and an approach for tackling present and future strategic challenges of drinking water infrastructure.

1.2 The framework and its elements

The strategic planning framework for drinking water infrastructure and its elements are visualized inFigure 1, which also indicates which chapter describes which stage of the framework. There are four main stages.
The first deals with the present state of the water infrastructure, how it has historically developed and the main drivers and patterns behind this development. Insight in these (historical) drivers and patterns enable strategic planners to better estimate, and thereby enhance their steering possibilities towards the desired future state of the water infrastructure system.

[1] These assumptions on how to perceive of and study futures are elaborated upon in chapter five.

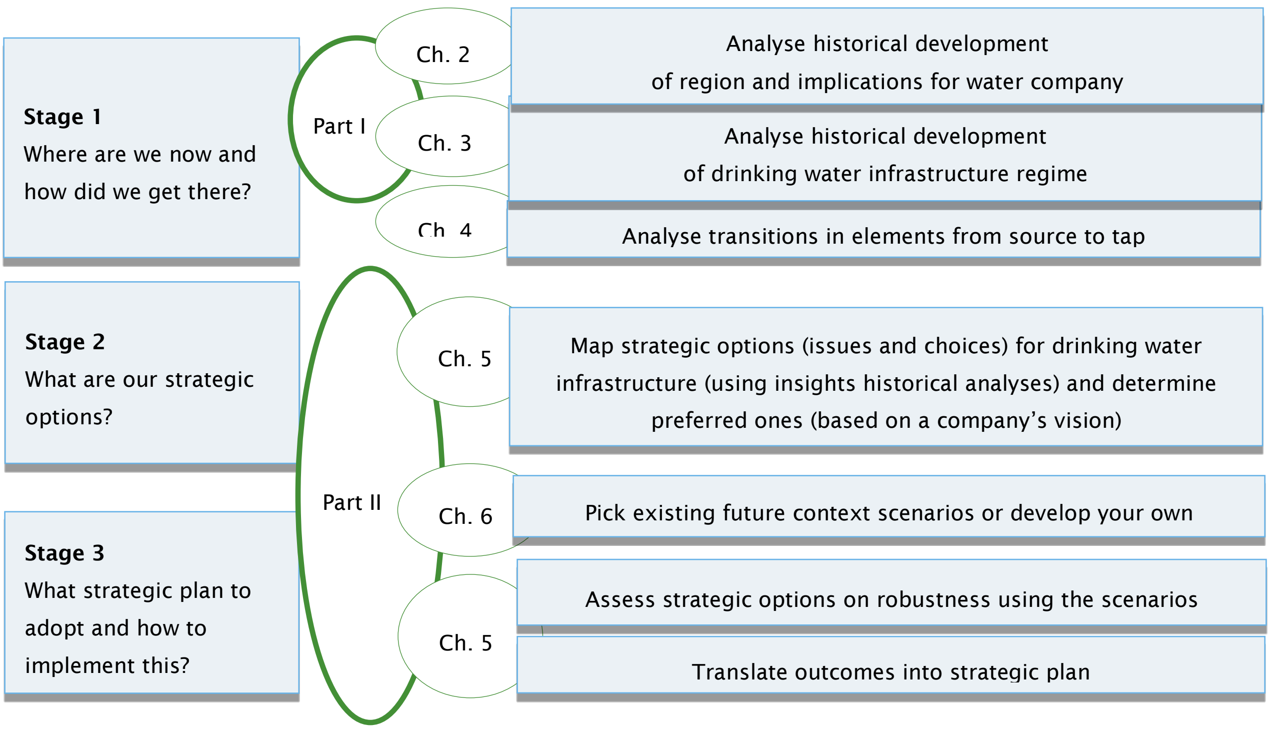


FIGURE 1 THE STRATEGIC PLANNING FRAMEWORK FOR DRINKING WATER INFRASTRUCTURE AND ITS ELEMENTS

The second stage is concerned with mapping the range of strategic issues regarding drinking water infrastructure. In line with the overall vision of the water company, and based on the insights gained in the first stage, a multidisciplinary team determines what are important strategic issues and choices for the entire drinking water infrastructure system. Then they prioritize strategic options in terms of preference, i.e. the options that best match the overall vision of the company.

In the third stage, strategic planners assess the robustness of all strategic issues and choices and decide what strategic pathway to follow. Assessing robustness is done by the use of external (context) scenarios, based on which strategic planners analyze and weigh the outcomes, resulting in favored strategic pathways. If a preferred strategic option proves not to be robust, and in order to avoid opportunistic behaviour, it is recommended to stick with the preferred choice and draw up a plan how to deal with the perceived conditions and factors negatively affecting the strategic option. Afterwards the question of how to implement and monitor the strategic pathway defined is tackled, including whom to collaborate with is addressed, as well as actions how to deal with emerging uncertainties and trends.

Before going into more detail how the book is structured and what the different parts and chapters entail, the next section briefly discusses some of the main theoretical starting points of the material presented in this book.

1.3 Theoretical starting points

Some of the key- assumptions and foci of this book have been described above, but the parts and chapters in this book draw on some (additional) theories and conceptual points of view that are briefly pointed out here. Theoretical and conceptual ideas and models that have been used for one or only a few of the studies will be explained in the respective chapters.

1.3.1 Socio-technical transitions

Generally, the book is concerned with *socio-technical transitions* –large and small– in drinking water infrastructure and how these can be studied, visualized and steered in strategic planning processes. In the chapters, we mainly draw on the multi-level perspective (MLP) to analyse socio-technical transitions (Geels, 2002). The MLP distinguishes three levels: niche-innovations, sociotechnical regimes and sociotechnical landscape (see 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 is the 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; see Figure 2).

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 2, 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 at the same time that transitions occur in the "socio-technical regime", the landscape changes and 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.

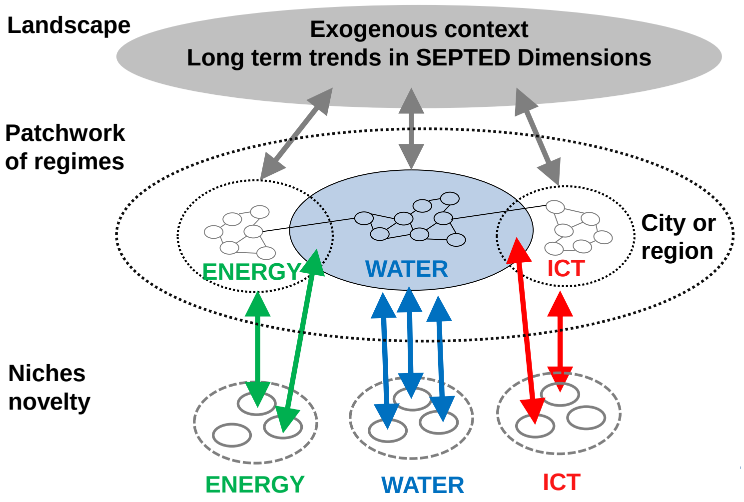


FIGURE 2 SCHEMATIC REPRESENTATION OF THE MULTI-LEVEL PERSPECTIVE (MLP) FOR THIS STUDY, INTERACTIONS BETWEEN THE INFRASTRUCTURE REGIMES IN THE CITY AND THE NICHES AND LANDSCAPE.

1.3.2 Systems thinking and spheres of influence

The framework presented in this book aims at providing strategic planners in water companies with guidelines, example studies and building blocks. In doing so, it is imperative to distinguish between different spheres or domains of influence from the perspective of water companies, and how they relate to one another. Systems thinking was used to define these spheres of influence. This means that a distinction is made and boundaries are drawn between an internal and external system, and a so called 'transactional' environment (Figure 3).

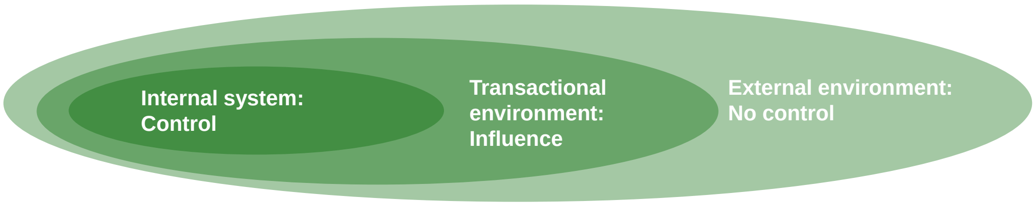


FIGURE 3 SPHERES OF INFLUENCE: INTERNAL, TRANSACTIONAL AND EXTERNAL ENVIRONMENTS (AFTER GHARAJEDAGHI, 1999)

The internal system encompasses the space and attributes that we assume drinking water companies have full or significant control over. Strategic decisions can generally be made and implemented without having to argue with third parties. The external system is determined by the interplay of different types of developments and trends (such as in the social, economic, political, technological, ecological and demographic domains, abbreviated SEPTED). It is assumed drinking water companies have no control over the external system. Whereas drinking water companies cannot influence those, or so we presume, they do impact on *their* operations, to varying degrees. In between the internal and external systems is a space we label "transactional". It is in this 'grey' area that water companies have no full control over their decisions and actions, as they depend on third actors to realize their will. They may decide to act in this space one way or another, and they often do so in a more implicit or explicit way, but they always do this in mutual interdependence.

1.4 Contents and structure of the book

Having outlined the central features of the framework and some of the main theoretical and conceptual starting points, this last section will describe in more detail what readers can expect to find and read in the book. The framework introduced above is composed of and provides different elements such as guiding principles, example studies and building blocks for strategic planning processes regarding drinking water infrastructure. These adhere to one part that deals with 'the past', another one that deals with 'futures' of drinking water infrastructures and a last one that combines all this in steps and recommendations that can be followed up in concrete strategic planning processes.

As some themes may be of more interest than others to readers, below one can find a special 'reader's guide' to the book (Table 2). It indicates relevant questions for strategic planners, associated themes discussed in the book and what one can expect to find or learn in a specific chapter. The chapters are briefly introduced after Table 2.

TABLE 2 A READER'S GUIDE TO THE BOOK

Are you interested in the question/domain of...		Read chapter	What to expect/ learn in these chapters?
...how (aspects of) drinking water infrastructure have developed historically?	At the landscape level/ context water companies operate(d) in	2	Understanding (trends in) drivers for change
	At the level of water company's service area	3	Specific drivers behind investments in water infrastructure
	Regarding infrastructure from source to tap	4	Examples of different types of transitions and their speed of change
...how to influence transitions?	At the level of water company's service area	3, 4	The actors in the different spheres of influence (see Figure 3)
	Regarding infrastructure from source to tap	4	That there is time and space to steer or adjust transitions
...how to deal with the future in strategic planning of drinking water infrastructure?	In the strategic planning process	5	How to design a strategic planning process
	In the realisation of strategic plans	4, 5	How to cope with (key) uncertainties and how to monitor these
	In a specific case study of a Dutch water company	5	Inspiring / telling example
...what future scenarios are, how they can be used in strategic planning processes and generic, ready-made scenarios	Building your own future scenarios	5	Process of and tools for building scenarios
	Enriching the generic, ready-made scenarios	6.2	How to make the generic, ready-made scenarios specific for one's own operating context
	Applying the generic, ready-made future scenarios	6.1	How to use the generic, ready-made future in one's own strategic process
.... where to find additional/ background information?		Part IV Part V	Additional and more extensive descriptions

The book consists of three parts, in line with the framework. The first is concerned with the present state and the historical development of drinking water infrastructure, the second with the strategic options/ dilemma's and how to assess those on robustness with the use of future scenarios and the third addresses the conclusions and recommendations.

1.4.1 Part I: historically informed strategic processes

This part contains three chapters. Chapter 2 is concerned with so-called 'landscape' changes (see Table 1) and the broad historical developments and trends in the SEPTED dimensions at the local, national and global levels. Major changes in one or more of these dimensions have had considerable impact on how water companies view the(ir) world and therefore, how they made decisions on water infrastructure. Chapter two describes some of these major changes and the impact on water companies and water management in the Netherlands. It provides an understanding in some of the fundamental drivers for change.

The focus of chapter 3 is on so-called 'regime' changes. The concept of 'regimes' in this book refers to a particular drinking water infrastructure system, which runs (or not) on the interplay of a myriad of socio-technical elements including pipes, pumps, operators and organizations (see also Table 1). Over time, such overarching regimes change, based on and driven by driving forces in both the landscape and the smaller elements of which it is composed. In chapter three a study example of this approach is given, highlighting how drinking water infrastructure regimes have changed in four Dutch urban areas, namely Groningen, Amsterdam, Arnhem/Nijmegen and Maastricht. It thereby indicates the drivers behind these changes, and how influencing such transitions took (and can take) place. The case studies here are summarized, more detail is found in part IV of this book.

In contrast, chapter 4 takes as the starting point of analysis changes in one or more of the socio-technical components that together make a drinking water infrastructure regime run. It gives a compiled version of a study of changes in specific parts of the infrastructure, namely in the field of extraction, treatment, distribution and consumption of water in the Netherlands. The value of this chapter for the overarching framework is not only the historical sketch and insights, but also, like chapter three, how such (mini) transitions have been and can be steered. The examples here are summarized, more detail is found in part V of this book.

1.4.2 Part II: Visualizing and planning for futures of drinking water infrastructures

This part is meant to give readers inspiration and tools for approaching futures of drinking water infrastructure in planning processes.

The first chapter of this part, chapter 5, provides guiding principles with which strategic planning for the future of water company's infrastructure can be carried out and the results of their application in some case studies. It describes and discusses assumptions for how to deal with the future in strategic planning processes and it provides a selection of methodologies and planning techniques, such as for the building of future scenarios. In the research project underpinning this book, these tools have been applied with the ten Dutch drinking water companies together, as well as with one water company in particular. The results that these processes generated are also discussed in this chapter.

Chapter 6 proceeds by providing water companies and strategic planners a concrete building block in the strategic planning process, namely four future context scenarios for cities and urban regions. Drawing on ongoing horizon scanning activities in the BTO and in participation with a transdisciplinary team of water researchers and practitioners, these scenarios present four plausible and internally consistent storylines of how future urban societies may look like. These can be used by water companies for testing the robustness of strategic choices. The scenarios are ready to be used by water companies as they are, but can even be of more use when they are enriched by trends and developments specific for the region of a particular drinking water company.

1.4.3 Part III: Conclusions and recommendations

Part III brings insights from the previous chapters together in conclusions and recommendations. It provides strategic planners with 'stepping stones' for setting up and implementing a strategic planning process for drinking water infrastructure. It provides learned lessons gained during the research project, as well as concrete recommendations on for instance team composition and the use of techniques. Lastly, some knowledge gaps and promising research questions are given that can be tackled in future research endeavors.

The conclusions and recommendations are based also on parts IV and V of the book. These last parts provide detailed background for further reading. Reading only parts I to III may suffice for most readers.

1.4.4 Part IV: Historical development of four Dutch urban drinking water infrastructures

This part provides the background to chapter 3. It describes in detail the case studies of the historical development of four different urban areas. This part ends with a more detailed discussion of the results, which is summarized in chapter 3.

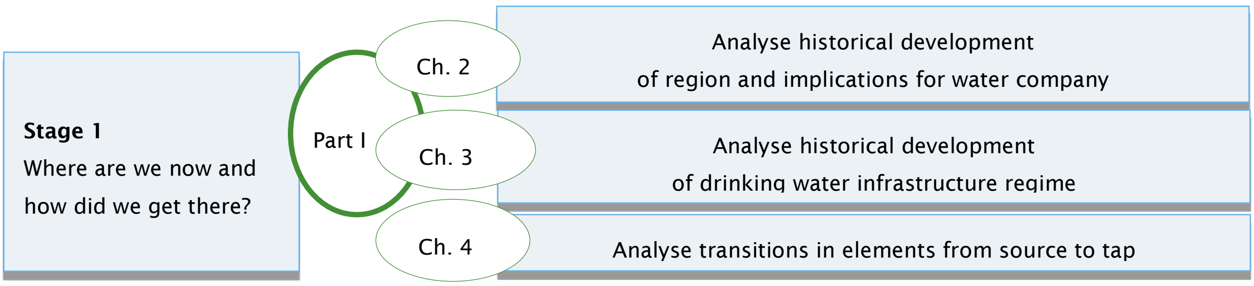
1.4.5 Part V: Transitions in the drinking water infrastructure – a retrospective analysis from source to tap

This part provides the background to chapter 4. It describes in detail the (Dutch) examples of transitions in drinking water demand, a change in design guidelines of drinking water installations, a transition from using chlorine as a residual disinfectant towards abandoning residual chlorine and a transition from using only ground water a source to preparing for an alternative surface water source. This part ends with a more detailed discussion of the results, which is summarized in chapter 4.

Part I

Historically informed strategic planning processes

The following part of the framework, and the accompanying chapters, will be described in Part I:



And the following questions addressed:

Are you interested in the question/domain of...		Read chapter	What to expect/ learn in these chapters?
...how (aspects of) drinking water infrastructure have developed historically?	At the landscape level/ context water companies operate(d) in	2	Understanding (trends in) drivers for change
	At the level of water company's service area	3	Specific drivers behind investments in water infrastructure
	Regarding infrastructure from source to tap	4	Examples of different types of transitions and their speed of change
...how to influence transitions?	At the level of water company's service area	3, 4	The actors in the different spheres of influence (see Figure 3)
	Regarding infrastructure from source to tap	4	That there is time and space to steer or adjust transitions

2 Landscape developments and their impact on transitions in water management, 1880 – 2015

This chapter is concerned with sketching changes on the level of the 'landscape', that is, the broader trends and developments that take place in a society and which influences the way water is and ought to be managed. Studying and making sense of such bigger external changes, and how they relate to one's 'internal' system (see Figure 3), is an important part in the broader strategic planning framework presented in the previous chapter. As the project on which this book is based was concerned with the Dutch drinking water sector as a whole, this chapter accordingly provides an analysis of landscape changes in the Netherlands (and 'the West' more generally) and how these have influenced (drinking) water management in the Netherlands over the past one and a half century.

The analysis in this chapter draws on Allan (2003), who distinguishes the following five phases or major paradigm changes on the landscape level:

- A 'premodern' phase (until approximately 1880)
- From industrial to reflexive modernity (1880 – 1970)
- The rise of environmental consciousness and the green movement (1970s onwards)
- The rise of free-market thinking (1980s onwards)
- Focus on institutions, governance and management (2000s onwards)

Allan (2003) describes how during these phases societies and its major actors have looked at and treated nature and specifically, water[2]. Each of these landscape phases and associated 'water management paradigms' know their own dynamics, (dominant) world views and conditions that for a great part determined what type of ideas and policies were or were not deemed relevant, legitimate and/or innovative. The core ideas of these five phases/paradigms are explained below and taken as basis for the description of (specific) influential landscape trends and developments that have been (and some still are) of importance to the Dutch context. These will then be related to changes in the way water and nature more generally has come to be seen and approached, and specifically to major (past) changes of and in the Dutch (drinking) water sector.

2.1 Premodern phase (until approx. 1880)

The premodern phase, that lasted until far in the nineteenth century, is characterized by a limited technological and organizational capacity. Securing essential goods for existence, on a local and regional scale, occupied a large share of the day for most people. Although history has seen sophisticated drinking water systems, such as those of Romans, many people depended long after these times on local and regional sources for their drinking water, notably rain-, ground- and/or surface water. Technical and hydrological knowledge only began to progress later in the Middle Ages and the development of advanced drinking water systems really kicked off after the start of the

[2] These landscape phases derive from so called 'modernity theory', an influential branch of sociological theory used to explain modernization processes in societies, and the stages they go through when advancing from 'pre-modern', 'traditional' societies to the highly developed and to some, 'civilized' nations of today – at least in the Western world where this study focuses on. Although the framework of Allan (2003) takes the professional field of irrigation and only part of the Western European geography as starting points, it is also a useful heuristic for interpreting how (aspects of) the Dutch drinking water sector developed and unfolded over the last one and a half a century, as we will see in this and the subsequent chapters.

industrialization, first elsewhere in Western Europe and later in the 19th century also in The Netherlands (De Moel et al., 2006).

2.2 From industrial to reflexive modernity (approx. 1880 – 1970)

The industrial revolution and the idea of modernization that came up in the second half of the 19th century quite radically changed the fabric of Western societies. Central in this phase was the notion of progress, building on the ideals of Enlightenment such as reason, ratio and science. This phase saw the emergence and fast growth of modern banking, different types of industries and public entities, as well as major breakthroughs in science and technology, which greatly spurred the modernization of society and the growth of the economy. This made for instance interventions in nature possible on an unprecedented scale, driven by normative views to control the hitherto 'unpredictable' nature and to adjust nature to the needs of modern man. Major (state) investments in large infrastructural works in various domains such as water and energy followed and these also had clear economic purposes, like in the straightening of rivers. But these were also opportunities to apply the newest technological and hydraulic features, which often became an end in itself, hence, the term 'hydraulic mission'. This view on nature and subsequent interventions is embodied especially well in water (flood) management during this time period. (Allan, 2003; Disco, 2002; Molle, et al. 2009, Mollinga, 2008; Koot, 2005).

Modernity also implied a move away from dirty and decease prone cities towards higher levels of cleanliness and hygiene for first the elite and later the mass of people. This is where drinking water comes in (along with other essentialities like sanitary services); advanced and integrated processes of extraction, treatment and distribution enabled an efficient and secure provision of large quantities of high quality water and would take away a major cause of (the spread of) infectious deceases like cholera. Such systems were first initiated by private funders and operators in cities and, following a strong perception that water (like other resources) should be available for the public at large, local and regional governments took over this function (Brown et al. 2009). The first drinking water system of The Netherlands emerged in Amsterdam in 1853, by 1900 some 60 water companies provided water to hundred cities and municipalities, but it was only until the late 1960s that almost every Dutch household was connected to a centralized drinking water system (De Moel et al., 2006).

Overall, this phase of industrial modernity contributed greatly to social welfare of people, particularly in the interwar period and after World War II. It created conditions for structural growth in population and life expectancy in The Netherlands. New economic sectors stimulated employment, especially in and around cities that during the early industrialization rejuvenated, expanded or came into being. New sectors brought new types of labour (e.g. administrators) and social classes (e.g. growth of middle classes). Based on class, religion and/or political views, people began to organize themselves in so called societal pillars, all having their own social institutions, from schools to newspapers (Manning & Bank, 2005). After World War II, a grand reconstruction program soon brought industrial production back to pre-War levels. This, in combination with other important milestones like the discovery of the large natural gas field in Slochteren at the end of the 1950s, heralded a period of rapid and renewed economic growth and prosperity and laid the foundation for the modern consumer society, in which citizens' increasing spending capacity and spare time enabled them to consume and recreate more and more intensely (Kromhout, 2007).

Industrial modernization came with a price however. A relentless pursue of 'progress', ever higher levels of economic growth and prosperity went hand in hand with severe and tangible environmental degradation and erosion of representative democracy more generally. Growing discontent eventually incited a new phase commonly referred to as "reflexive modernization" (Beck, 1992). Under this phase, the assumptions and ideals of industrial modernization were critically assessed or even rejected, most prominently from three dimensions, namely from an environmental, free market economic and institutional/ governance perspective. The impact of these three movements on a landscape level and specifically for the Dutch (drinking) water sector will now be explored.

2.3 Dimension I: environmental consciousness and the green movement (approx. 1970/1980 onwards)

The end of the 1960s and beginning of the 1970s saw a growing environmental awareness in society, as well as more democratization and citizen involvement in political and policy decision making. The social and green movements took advantage of this momentum and pointed out the negative consequences of a century of industrial modernization on the environment and, more generally, on the social fabric of society. Such concerns and sentiments of initially minor movements were widely shared in society and the government too felt it could no longer move on like they commonly did. They decided on (more) regulation on industry and other sectors, for instance aimed at the reduction of harmful emissions.

Normative views on nature changed due to these developments, which had repercussions for the water sector at large. The belief that nature could and should be controlled, made way for a more nuanced vision, one that stressed nature's fragility and uncontrollability and that (effects of) interventions in nature are highly uncertain. The founding of the Club of Rome and its well-known report *Limits to Growth* published in 1972, followed a decade and a half by the Brundtland Report, effectively raised environmental concerns up to the highest political stages and formed the starting point for mainstreaming the discourse of sustainable development. On a national level and specific to water, the introduction of the Law on Water Surface Pollution, with water quality as main concern, nicely reflects an environmental issue that formerly received little political attention and which now had become a prime concern (Disco, 2002). Environmental laws and guidelines like the polluter pays principle were introduced and industry was compelled to obtain licenses for wastewater discharge. The building of modern wastewater treatment plants also took off and these measures combined proved highly effective in improving (surface) water quality, which also benefited drinking water companies in producing drinking water. The grand water (flood) management projects that were commonly proposed and executed without any meaningful alterations, increasingly received (critical) attention from citizens and special interest groups alike, demanding their voices to be heard and projects to be altered or abolished altogether (Simissen, 2009).

Although environmental consciousness is a very noticeable development during these decennia, with particular effects on how nature and water is perceived and managed, the 1970s and 1980s of course knew many more major landscape trends and developments. The Cold War, in its peak those days, entailed not only a conquest for global hegemonic power, but also an ideological struggle for supremacy of either the capitalist or communist (economic, cultural) system – although neither system was homogenous and both knew many variants. Economies had also become increasingly interconnected and oil-dependent. Two oil crises in the 1970s, in combination with other factors, therefore led in the early 1980s to the deepest recession since the one in the 1930s, with huge implications for national economies and the daily lives of many in Western Europe and the Netherlands (Bhageloe-Datadin, 2012). It is from here on that, next to the environment, another dimension rose to prominence: the free market economy and free market thinking.

2.4 Dimension II: free market thinking (approx. 1980s/1990s onwards)

During the phase of industrial modernity, the State played a major role in stimulating and steering the market economy. This came under attack by neoclassical economists at the end of the 1970s and beginning of the 1980s, who revived the idea of the free market economy in the West[3]. In their vision, the State should play only a minimum role in steering the economy and instead leave that to the 'invisible hand' of the market (see Smith, 2010 [1790]) and its assumed self-regulating capacities. These economists claim this to be the best way to create welfare and distribute income and wealth. This variant on liberal thought, often referred to as *neo*liberalism, reigned especially during the 1990s, after the fall of the Berlin Wall in 1989. Well-known manifestations of this dimension were acts of privatization and deregulation, most prominently in the financial sector that grew exponentially from then on. Capital that became available as a consequence, gave an enormous boost to technological and other innovations, especially in the then upcoming and fast growing ICT sector. All this led to high rates of economic growth in the second half of the 1990s.

On the longer term, the influence of this dimension on society and specifically nature and water, comprises the less tangible (free) market based thinking and a growing predominance of financial-economic reasoning within not only private, but also public organizations (Veenswijk, 2005; Harvey; 2005). From this point of view, nature is not only seen as having an intrinsic value on which humankind depend, but also, or even more, an economic good or commodity. In line with these thoughts, water became formally recognized as an economic good in the Dublin Principles defined in 1992 (ICWE, 1992). Examples of market based approaches applied to nature/ water are most prominently the cap and trade system to reduce carbon dioxide emissions, but also include the more recent attempts of attaching a price to natural resources (monetarization) or applying economic principles to (reducing) water use.

The Dutch drinking water sector adopted similar market based- and private sector principles in their implementation of the so called New Public Management (NPM) concept. In short, NPM entails the trend of (semi)public organizations becoming increasingly molded after private organizations, assuming the latter to be superior in terms of efficiency and ways of working (Hernes, 2005). As such, water sector organizations were not privatized, like those in the telecom and other public sectors, although fierce political debates at the end of the 1990s between those in favour of and others opposing water privatization in The Netherlands did take place. Instead, liberalization and deregulation of drinking water companies took place, with NPM as a leading vision. Government-led provision of water for the sake of universal coverage were gradually replaced by autonomous, semi-public utilities whose drivers to operate changed, for instance towards more efficient and market like service delivery and securing or improving their "market position". These drivers underpin also many of the mergers in the drinking water sector roughly after the 1980s, whilst before that, mergers of municipal water utilities into provincial ones were commonly instigated by the government (Schwartz, 2011).

NPM influenced not only drinking water companies, but water management more generally. Rijkswaterstaat, for instance, underwent multiple major reorganizations, with great reductions in labour and budgets, legitimized on the promise of becoming more efficient and service-oriented whilst claiming the private sector could better do the job than the organization itself. Hence, outsourcing and competitive tendering became the norm at Rijkswaterstaat (Metze, 2010; Van den Brink, 2009).

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[3] Economic policy under industrial modernity in the West was strongly influenced by the renowned economist John Maynard Keynes, especially during and after the great recession in the 1930s. Milton Friedman and others at the Chicago School of Economics were amongst the main economists designing the doctrine of (neoliberal) free market economy, of course building on the principles of neoclassical economy as established by Adam Smith and others. Their ideas were first adopted and implemented on a larger scale in Chili under the Pinochet regime, but really gained momentum after President Ronald Reagan of the United States of America and Prime Minister Margaret Thatcher of the United Kingdom implemented the neoliberal political agenda from the early 1980s onwards. In The Netherlands, the then Prime Minister Lubbers adopted similar principles for his cabinet's (economic) policies. During the second course of the 1990s, the two administrations of Prime Minister Wim Kok tried to reconcile neoliberal free market principles with those of the social democratic movement in the so called "Third Way" (see Giddens, 1998).

This dimension, amongst other factors, also pushed forward the much debated shift from "government to governance". This basically implies a shift in power from the State [government] as central actor in making and implementing (water) policies, common during the industrial modernity phase, towards a much more fragmented dispersion of power over a diversity of actors on different levels, from the national to local, supranational and global levels [governance] (Swyngedouw, 2006: 58). Thus, (yet) another dimension emerged at the end of the 1990s, the institutional/governance/management paradigm (Allan, 2003).

2.5 Dimension III: focus on institutions, governance and management (approx. 2000 and onward)

From roughly the start of the 21st century, increasing attention went to institutional factors and aspects of governance and management. Politics and policies of the 1980s and 1990s, combined with the rise and growth of ICT technologies such as the PC, mobile phones and the Internet, spurred the already ongoing process of globalization. Economically, this meant that national economies and financial sectors became even more entwined than they already were, further stimulating international trade and growth. Politically and policy wise, levels and actors other than the nation state grew in importance. That is, on the one hand, institutions on a 'higher' (e.g. supranational) or 'lower' (e.g. city scale) level are often attributed increasing decision-making powers (Ray, 2007; Walters, 2001). On the other, the political and policy landscape had become increasingly fragmented, with non-profit and private actors increasingly filling up the vacuum left by the State in the 1980s and 1990s. The effects of neoliberal (economic) policies also became much more clear and visible. Firstly, while it created immensurable wealth, its distribution turned out to be highly uneven in social and geographical terms. Secondly, it led to growing pressure on the environment and (the use of) fossil fuels, as well as accelerated climate change. Lastly, it soon turned out that the high rates of growth were mainly based on speculation, which has been a major cause of the "dot-com bubble" in 2002 and, after a short economic recovery, of the credit- and debt crises in 2007 and 2009 (Harvey, 2005; Piketty, 2014; Castree, 2011).

All these landscape developments made society and the problems and issues it faces appear increasingly complex. Understanding grew that the drivers and causes of these problems were multiple, highly interconnected and multidimensional. This in particular spurred a depart from technocratic views, common during earlier phases, to a growing appreciation of the deep social, institutional and political roots of these problems. On the assumption that the nature of these problems is multidimensional, solutions should also be of an interdisciplinary kind. Therefore, actors have become increasingly concerned with seeking approaches and solutions in the institutional and 'social' sphere, next to those technological or economic. Because society had also become more fragmented and 'networked', such institutional, and especially management, approaches came to be addressed more often in so called governance processes or arrangements. This is reflected in now prevalent ideals underpinning many of these governance arrangements, which are often 'photo negatives' of the problems we face nowadays. Thus not *fragmented*, but *integrated*. Not *apart*, but *participatory* and, lastly, not to the benefit of the minority, but *inclusive* of everyone (Molle, 2008; Allan, 2003). This dimension blends in with the other two in the popular credo of People, Planet, Profit, which is used by many organizations in their (rhetorical) quest for win-win(-win) solutions.
In the (globalized) world of drinking water the institutional dimension can be traced, often again in relation to the environmental and economic dimensions. A typical example is the often cited quote of the World Water Council on a so called global water crisis, which they say is "…not about having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people –and the environment– suffer badly" (Cosgrove and Rijsberman, 2000: xix). It is indicative of how many other water actors currently perceive of the water problem, i.e. that it not so much a supposed lack of adequate technologies or expert knowledge, as it is a question of how to best manage our water resources and drinking water services. That this latter question is an inherently political and ideological one, and thus deserves (political) debate, is still little acknowledged (Swyngedouw, 2011; 2013). Rather, normative views on how best to manage water are presented as 'best practice' or as uncontested statements assuming consensus.

This is where the economic dimension comes in once again, since one of the most powerful such statements is that water should be everybody's *business* – gently stressing water as an economic resource.

Today the three dimensions or paradigms are still very influential. From rather small, alternative groups in the periphery who claimed to be defending the environment, being 'green' has now almost become a prerequisite if one wants to be taken seriously. Economic and market based approaches for various types of issues, be they environmental or related to water or health, remain popular in governance and policy circles. A good example hereof, in the drinking water sector and elsewhere, is the emphasis on not only developing and implementing (public) goods for the sake of its *use-value* to the public, but also on its *exchange-value,* i.e. bringing these to the market (*vermarkten)* for reasons of accumulation of surplus-value and additional income, often in public-private constructions. And questions of governance and institutions are gaining ever more attention, up to the point of becoming all-encompassing terms that risk losing analytical and explanatory value. Nevertheless, major and often cited landscape trends such as urbanization, climate change or the (fragmented) network society presents us with many institutional challenges, from questions related to policy scales and bottom-up initiatives, to new and innovative management approaches.

2.6 Conclusions

This chapter provided an overview of major paradigm changes in the Netherlands (and Western Europe more generally) and how those have influenced perceptions on nature and the management of (drinking) water. Central during processes of industrialization and so-called modernization in the early and mid-19th century, was the 'controlling' of nature and water through engineering, in support of economic well-being. This came to be challenged with the rise of environmental movements in the 1970s, who pointed out the detrimental socio-ecological effects of industrialization. "Thinking and doing green" has only become more influential, a trend that can be witnessed in the water sector. This has come to be accompanied by two other major paradigms: those associated with the (free) market and with institutions. The former points at the rising power of market and financialized thinking and –mechanisms, the latter with a broader embracement of the view that institutions matter in the management of natural resources, next to the hitherto predominant focus on technology.

Albeit brief and inevitably incomplete, this overview indicates that sociotechnical transitions in the water sector and hence, in water infrastructure, do not 'just' occur, but are intimately related to and influenced by broader societal structures[4]. In this case, the Netherlands as a whole was taken as study object. Those intending to study (the impact of) broader landscape changes as part of their planning process may do the same for and thus limit the analysis to the region or city of their concern.

[4] Following from what in social theory has a well-established position: debates on "structure-agency".

3 Urban infrastructure ‘regime’ transitions

The focus in this chapter is on transitions in drinking water infrastructure on the “regime” level, that is, on the level of the city or the urban region. This perspective is useful for gaining insight in how integrated drinking water infrastructure as a ‘system’ developed in a particular city or urban region over time and the drivers behind such change. Based on that, planning for maintenance works or other types of interventions in the city can be significantly enhanced. In the research project, four cities in different parts of the Netherlands have been examined from this perspective, namely Groningen, Amsterdam, Nijmegen/Arnhem and Maastricht. These case studies have been described in detail in part IV of this book “Historical development of four Dutch urban drinking water infrastructures” (Chapters 8 - 13) and will be briefly recalled here, followed by an analysis of the (pattern in) drivers behind these changes.

3.1 Introduction and short theory recap

Drinking water infrastructure systems comprise various subsystems from source to tap, i.e. water extraction, treatment, and distribution systems, and can be considered in an integrated and holistic way. The drinking water infrastructure should be considered a socio-technical system, whereby its physical components are inextricably linked to social and organisational processes, such as its design and management. As explained in chapter 1, a transition can be defined as a change from one socio-technical configuration to another, involving substitution of technology as well as changes in other elements, such as practices, regulation and symbolic meaning (Geels, 2002). The Multi-Level Perspective (Geels, 2002) distinguishes between niche-innovations, the sociotechnical regime and sociotechnical landscape. Using these three levels, the different factors and actors that influence a transition can be traced and described, as well as their interrelations. Transitions can be related to the changes of an integral drinking water infrastructural system (breadth-oriented analysis, this chapter), or they can be related to one specific socio-technical aspect of an entire drinking water system (in-depth analysis, chapter 4). Transitions are characterized by the extend of an adoption, the rate of change, the drivers for change and the spheres of influence. The spheres of influence distinguish between an internal and external environment and a transactional space. The internal system comprises of all those infrastructural aspects 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.

3.2 Historical development of four Dutch cities and the drivers behind change

In order to find the major drivers for transitions in drinking water systems, we studied historical infrastructural development of four different Dutch cities and we identified the drivers behind these changes. We studied the major investments in the primary drinking water infrastructures, that is abstraction, treatment, storage and distribution, of the urban areas of Amsterdam, Groningen, Arnhem-Nijmegen and Maastricht in the past one and a halve century. Also, we determined whether the investments were driven by internal, transactional or external (f)actors. All incentives for 225 identified investments were classified into a limited number of 23 drivers. The occurrence of the drivers was analysed for each city and for three time periods in order to search for patterns or trends in the driver occurrence. Next, a summary of the main characteristics and developments of the drinking water infrastructure of the four Dutch cities is provided.

3.2.1 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.
For more details see Chapter 9.

3.2.2 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 20^{th} century. The municipal water companies were acquired by a private enterprise at the end of the 20^{th} 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.
For more details see Chapter 10.

3.2.3 Infrastructural development Maastricht

The basic set-up of the drinking water infrastructure in Maastricht was 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 21^{st} 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 21^{st} 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 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.
For more details see Chapter 11.

3.2.4 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 upcoming 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 today only water cycle company of the Netherlands.
For more details see Chapter 12.

3.3 Drivers of change and change in drivers

The incentives for the 225 identified investments were clustered into and classified by 23 different drivers. The Table 3 presents the drivers that were found. The driver codes are used in Figure 4 and Figure 5, for more details see Chapter 13.

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 suitable drinking water sources and the increasing customer connectivity and water demand in the early decades. The water demand is found to be an important driver, but its relative occurrence decreases over time. This observation is in accordance with the landscape analysis provided in chapter 2, in which the modernization of society and the 'hydraulic mission' were amongst the key driving forces until the seventies, and related to this, an aimed for and accomplished connectivity rate of almost 100% in the late 1960s. Investments induced by the merger of municipalities and larger scale companies, and the importance of environmental impact and costs occurred in the following later decades. This observation, too, is in accordance with the landscape analysis of chapter 2 which shows an increased environmental consciousness from the 1970s and a growing (perceived) need for cost efficiency, from the 1980s onwards. Despite the fact the considered cities are embedded in the same landscape and common generic drivers are found for these cities, its effects on the development of the infrastructure of the cities are also significantly influenced by local factors.

TABLE 3 DRIVER CLASSIFICATION AND DRIVER CODE

Driver description	Driver code
Water quality (raw water or drinking water quality)	WQ
Availability of source water (related to capacity or quality)	AVB
Water demand or production / distribution capacity	WD
Security of supply (related to water demand)[5]	SEC
Water pressure in the distribution net	P
Water supply plan	SUP
Geographical or climate related factors	GEO
Governmental or provincial policies, laws, or Water Decree	POL
Influenced / imitated by third parties	3rd
Customer related	CUST
Scarcity of materials	SCAR
(In)dependency of other parties	DEP
Technological development, the availability of new technology	TECH
Renovation (because of age, or rate of failure)	RNV
Costs	€
Investment- and project planning / timing	PLAN
Dependency of historical infrastructure (continuation of existing infrastructure)	HIST
Contracts with clients or other parties	CONTR
Operational reasons	OP
Organizational (mostly related to merger and acquisition)	ORG
Image (or customer confidence)	IMG
Energy (cost related)	E
Environment, sustainability	ENV

The relative driver occurrence for the period of one and a half century is presented for the four cities in the spider plots below. The identified absolute number of drivers for the investments in this period was 117 for Amsterdam, 70 for Groningen, 90 for Maastricht and 88 for Nijmegen-Arnhem.

[5] 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.

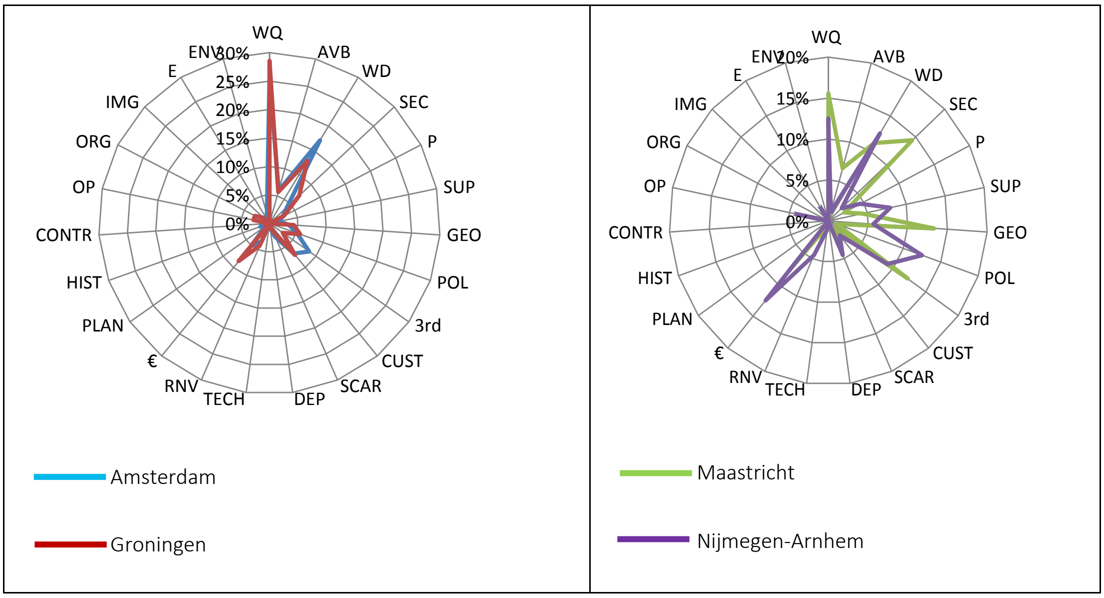


FIGURE 4 RELATIVE DRIVER OCCURRENCE FOR FOUR DUTCH CITIES. CODES REFER TO TABLE 3

The driver occurrence pattern of the two surface water treatment systems show differences, and the pattern of the two groundwater treatment systems show differences as well. Despite these differences, the following pie charts combine the driver occurrence patterns for Amsterdam and Groningen on the one hand, and Maastricht and Nijmegen-Arnhem on the other hand in order to visualize the change in driver occurrence patterns over time.

<table>
<tr><td>Period</td><td>Surface water

(Amsterdam and Groningen)</td><td>Groundwater

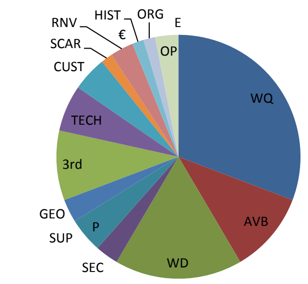
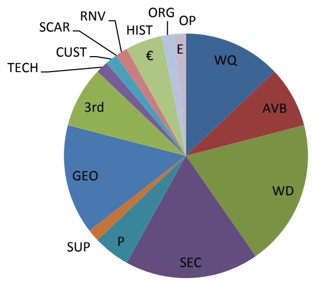
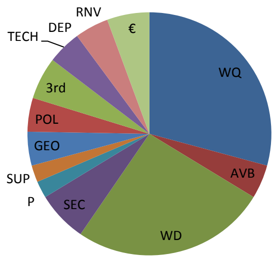
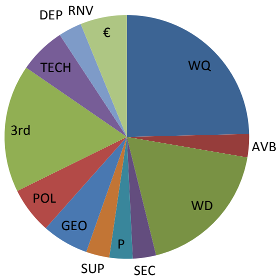
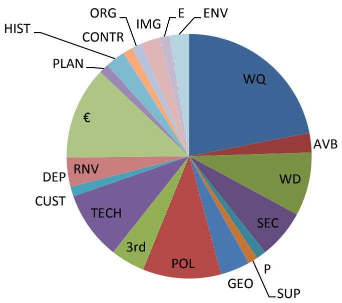
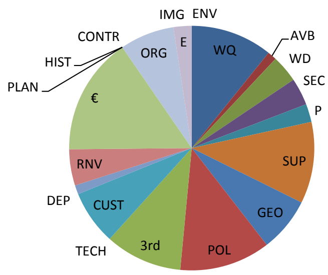
(Maastricht and Nijmegen-Arnhem)</td></tr>
<tr><td>< 1960</td><td>
</td><td>
</td></tr>
<tr><td>1960 - 1985</td><td>
</td><td>
</td></tr>
<tr><td>1985 - 2014</td><td>
</td><td>
</td></tr>
</table>

FIGURE 5 TRENDS IN DRIVER OCCURRENCE RATES OVER TIME, ADDED UP FOR SURFACE WATER SYSTEMS AMSTERDAM AND GRONINGEN AND GROUNDWATER SYSTEMS MAASTRICHT AND NIJMEGEN-ARNHEM. DRIVER CODES REFER TO TABLE 3.

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 of source and treatment 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 for similar studies, it is recommended to analyse at least a period of half a century to identify trends or differences in the occurrence of drivers as well as to identify transitions in integral infrastructural drinking water systems. This, in contrast to the transition of one specific sub-system or one asset-type, which typically takes two or three decades, as will be shown in chapter 4 (also see part V Transitions in the drinking water infrastructure – a retrospective analysis from source to tap, Chapters 14-18).

Rate of system change: inertia and flexibility

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. Also the transport pipeline system connecting the treatment plant to the cities was gradually expanded to meet the growing water demand and guarantee a secure water supply, but the basic outline of the transport pipeline system was rather constant due to the steady situation regarding the location of the treatment plants and the cities.

Many of the groundwater production facilities of the cities of Arnhem, Nijmegen an Maastricht have always existed since the establishment. As opposed to the location of the surface water treatment plants of Amsterdam and Groningen, some groundwater extraction sites near Maastricht, Arnhem and Nijmegen were abandoned because of the search for alternative groundwater sources or because the original extraction was located in the city center.

Generic landscape and drivers but local implications

The surface water treatment facilities of Amsterdam and Groningen have shown a continuous adaptation and improvement since their establishment, anticipating on changing source water conditions and striving for improvement of drinking water quality, whereas the groundwater production facilities of Arnhem, Nijmegen and Maastricht supplied its water without or with very limited treatment until the 1980s.

Hence, 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 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.

The analysis of the sphere of influence of drinking water companies shows that the majority of the investments is driven by factors perceived as external 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. 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.

3.4 Historical drivers versus future uncertainty factors

Examining the historical development of four Dutch drinking water systems revealed 23 drivers for change. Some of the drivers were identified as relevant throughout the existence of centralized drinking water supply systems, such as water quality and water demand. Some drivers only occurred a few times. Also, we found some trends in the occurrence rate of drivers over time. But how do these 'historical' drivers relate to drivers that are perceived to be influential on drinking water infrastructure in the long-term future?

Together with a group of Dutch water professionals and researchers, ten uncertainty factors have been identified that they think will likely have significant impact on a water company's operation, and the way they invest in or

operate drinking water infrastructure. Identifying these uncertainty factors was part of a process of scenario planning, the outcomes of which are fully described in chapter 5. However, it is interesting to know the importance of those uncertainty factors when seen from a historical perspective, i.e. how they relate to the outcomes of and the drivers identified in the historical study of this chapter. Therefore, in Table 4, the ten key uncertainty factors are given in the first column, and how these relate to the historical study in the second column.
Like the studies in this chapter indicated, drivers for investment in drinking water infrastructure have changed over a longer period of time, influenced by developments at the 'landscape level' (chapter 2). The Table 4 shows that in the future, compared to developments in the past, three groups of drivers may drive investments in drinking water infrastructure:

1 Drivers that have always been influential, and will likely remain so in the future, such as the ownership and organisation of the water company;
2 Drivers that have gradually become more influential, but that will likely become only more important, such as importance attributed to sustainability, the availability of resources and climate change;
3 Drivers that have played no or a very minor role in the past, but will likely become increasingly significant for water infrastructure decision-making, such as trust in water company, the regulatory framework and political stability.

Surely, the list and the drivers are not exhaustive; these drivers that have been identified as important in a particular project, in the context of the Netherlands and for Dutch drinking water companies. But they do point out the usefulness of not only studying past drivers, but also potential future uncertainty factors that may affect (investment in) water infrastructure and how the two relate. As opposed to established and well-known drivers, emerging and new ones (driver group 2 and 3) require strategic planners to consider how they might impact on their operations and investment decisions and draw action plans on how to achieve a certain vision or mitigate certain undesired or potentially harmful developments.

In doing so, the question is whether a particular driver is completely out of control to the water company or that it might somehow be influenced for instance by working together with third parties or influencing the public perception. A factor such as political stability may well impact on a water company's operation, but cannot be influenced, whereas trust is something that can to some extend be influenced. Chapter 5 will provide in more detail how water companies can identify such factors and how they can strategically plan in the context of an uncertain future.

TABLE 4 UNCERTAINTY FACTORS IN A HISTORICAL PERSPECTIVE

Key external uncertainty factor identified as having major impact on drinking water companies in the (long-term) future	Uncertainty factor in historical perspective (vis-à-vis the outcomes of the historical analyses)
Trust in drinking water company	Trust in drinking water companies was not found to be a driver for investments.
Importance attributed to sustainability	Sustainability ('ENV') was found to be a driver for investments in a few occasions in the last decades. The decision to invest driven by environmental concerns was assessed to be an internal choice. In the future, society is likely to expect drinking water companies to increasingly operate in a more sustainable way. Therefore, the sphere of influence is shifting from internal to transactional.
Water demand	Water demand was found to be a very important driver. In the first period of study – until after mid-20th century, water demand was one of the most frequent found drivers for investment, and was met by an increase in connectivity. The driver was assessed to be an external factor in the historical study. However, drinking water companies could influence the water demand to some extend (which would rather make it a 'transactional' driver) by discouraging water usage by means of campaigning or tariff structure manipulation, or stimulating water usage in industry or large-scale consumers by means of account managing and campaigning or tariff structure manipulation.
Regulatory framework	Regulation was not found to be a driver for investments.
Ownership and organizational structure of water entity	The merger between municipalities, private enterprises and provincial water companies was found to be an important driver for investing in and changing the water system. The decisions to invest because of organizational changes or to changes in the organizational structure (through merger, acquisition) was assessed to be an internal choice or a transactional choice respectively. Important to know for drinking water companies: Decision to merge is mostly transactional, although EU/governmental laws can initiate, stimulate or accelerate this process. Decision to change the water system (by investing) after the merger is often an internal choice.
Political stability	Political stability in drinking water companies was not found to be a driver for investments.
Availability water and other resources	Availability is characterised by quantitative and qualitative availability and has been a driver in the past. The availability of both surface- and groundwater is greatly affecting the water system infrastructure.
Pressure on/ use of the underground	Use of underground was not found to be a driver for investments, although '3rd parties' was found to be a driver for investment. And in previous times there were less people and hence, less infrastructure, but nowadays, space is running out.
Climate change	No driver that was perceived influential (far) in the past. Indirect through resource availability and geographical factors (river, hill, availability of groundwater and its quality, availability of surface water and its quality)

4 Transitions in water infrastructures from source to tap

The previous chapter looked at how drinking water infrastructure historically developed in a city as a whole, taking all types of drinking water infrastructures and their integration into consideration. This chapter, in contrast, takes a rather 'disintegrated' but in-depth view on particular selected parts of the total infrastructure and how transitions in these occur. This can in itself be valuable for strategic processes that focus solely on one or some parts of the larger infrastructure system, but it can also be fruitfully combined with the other approaches in the previous chapters in studying the occurrence of transitions. In the research project this book draws on, one socio-technical transition was studied in each of the different parts of drinking water infrastructure, from source to tap.

The transition regarding the drinking water source was about changing from a 100% groundwater extraction to a mix of ground and surface water extraction. The transition in the treatment was the change towards a chlorine free drinking water production and distribution in the whole of the Netherlands. A third transition was the change in practices and guidelines for the design of drinking water and hot water installations. The last transition that we considered was at the tap: the change in domestic drinking water demand.

This chapter briefly sums up what these different studies entailed and what they combined produced in terms of results and insights.

4.1 Models to analyse and steer micro-transitions

Socio-technical transitions in this chapter have much in common with the so-called "niche-innovations" in the multi-level framework of Geels (2002). Transitions on this 'micro-level' can be explained by the S–curve model that outlines the diffusion of innovation (see Figure 6).

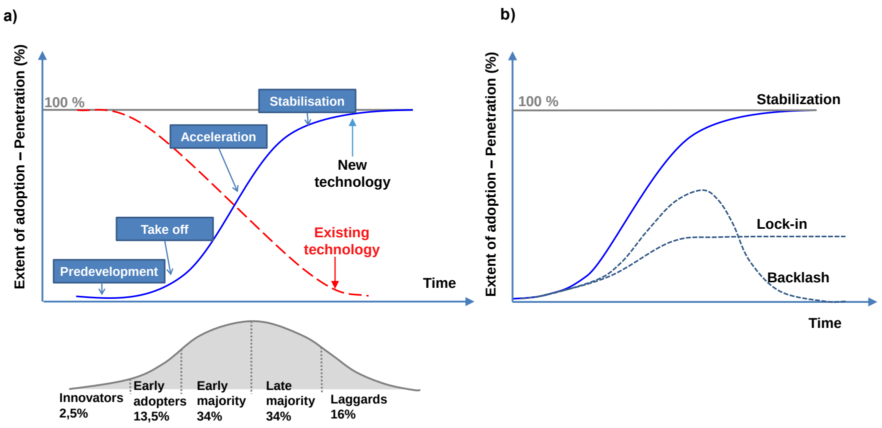


FIGURE 6 SCHEMATIC DESCRIPTION OF TRANSITION TRAJECTORIES A) SUCCESSFUL TRANSITION, B) RESTRICTED OR FAILED TRANSITION TRAJECTORIES (AFTER ROTMANS ET AL., 2001)

In this model, four stages can be identified: i) a "predevelopment" phase of 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; and 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; different trends and factors interact and innovation can “lock-in” or “backlash”, (Figure 6b). 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.

To what extent can transitions on the ‘micro-level’ be managed or steered? Seeing transitions as evolutionary processes that mark possible development pathways, the direction and pace could be influenced by slowing down or accelerating phases, as indicated in Figure 7. But to slow down or accelerate phases, it is important to understand what (technical, economical, etc.) factors drive the transitions and whether these factors are or are not within full control by the water company (internal or external system, Figure 3) or that they lie within the ‘transactional’ environment, whereby water companies do not have direct control over factors but may, for example through collaboration or lobbying, influence other organisations or individuals to change circumstances in a certain (for them beneficial) way.

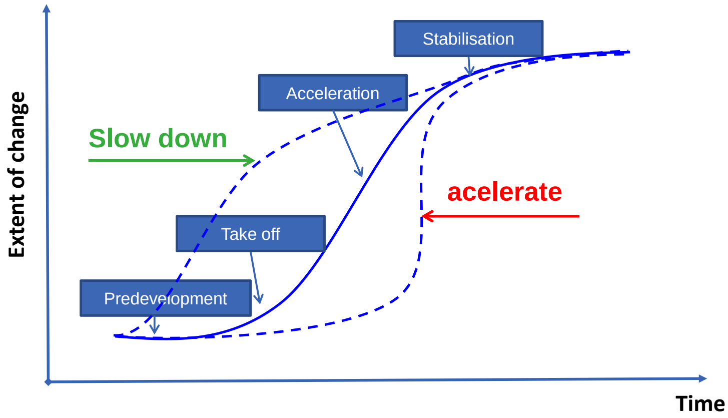


FIGURE 7 POSSIBLE DEVELOPMENT PATHWAYS IN A TRANSITION PROCESS

4.2 Socio-technical transitions in particular drinking water infrastructures

4.2.1 Introduction

An in-depth analysis was done on four relevant transitions in the Dutch drinking water infrastructure, covering the route from source to tap. The transition regarding the drinking water source was about changing from a 100% groundwater extraction to a mix of ground and surface water extraction. The transition in the treatment was the change towards a chlorine free drinking water production and distribution in the whole of the Netherlands. A third transition was the change in practices and guidelines for the design of drinking water and hot water installations. The last transition that we considered was at the tap: the change in domestic drinking water demand. What follows is a brief background on these studies, after which they will be analysed in terms of extent of adoption, rate of change and drivers for change and how these were steered.

4.2.2 Source: from groundwater only to groundwater and surface water

Predevelopment

In the Netherlands approximately two thirds of the drinking water is produced from groundwater and one third from surface water. Traditionally, there has been a division between pure groundwater water companies, which only use groundwater to produce their drinking water, and drinking water companies that (also) use surface water sources. Both Brabant Water (then WOB) and WML, prior to the transition period, used exclusively groundwater for the production of drinking water.

There were a number of macro-level triggers that got the transition underway (see also Chapter 2):

1. Expected increase in demand: starting in the 1970s, a strong increase in water demand was expected. This was driven by population growth and economic growth leading to an increased per capita demand.
2. Decrease in demand: In 1970, the Pollution of Surface Waters Act came into effect. This meant an incentive for the industry to produce less waste water, and this led to using less drinking water. The 1970s oil crisis meant an incentive to save energy, and using less hot water was one of the ways to reach this goal (see also § 4.2.5).
3. Decrease in groundwater availability: With the increasing concern for nature and the environment (the Nature Conservation Act of 1967; *Limits to Growth* in 1972), the consequences of groundwater abstraction were more apparent. There would be less groundwater available for agricultural crops, and semi-natural and natural vegetation, leading to harvest losses and changes, or the impoverishment of species composition in semi-natural and natural vegetation. In the Second National Drinking and Industry Water Structure Plan of 1985 (enforced by EU legislation), the alternative water supply options Heel-Panheel (WML) and the Maaskant infiltration (Brabant Water) were specifically referred to by name. The planning actions showed a need here to research alternatives to groundwater abstraction.
4. Abstraction from several small, shallow abstraction sites that were difficult to protect and where water quality issues (Nickel, Nitrate) would be too costly to solve, lead to a reconsideration of the source water. This applied only to WML.

Take off

The combination of growing demand and diminishing possibilities of expanding groundwater abstraction forced the provinces of North-Brabant and Limburg, and Brabant Water and WML water supply companies, to look for alternatives.

Around 1989 Brabant Water found that it needed an extra of 10 million m^3/year above the groundwater abstraction license. The Maaskant Filtration Project (PIM) was then considered the best alternative. It came the closest to groundwater, because it involved soil passage. PIM was planned for the banks of the river Meuse, but the Waal River also flowed close by at the location which provided a surface water backup.

Around the early 1990s, WML, under pressure from the province, decided to start preliminary work on surface water abstraction in Central-Limburg. Even though it became clear in the mid 1990s that water consumption would increase less than originally forecasted, WML decided to go ahead with surface water abstraction. Internal drivers, such as scale benefits – and thus cost-efficiency – flexibility and a quest for innovation, led WML to adapt and implement surface water abstraction.

Acceleration

Brabant Water: In the first half of the 1990s, an Environmental Impact Assessment (EIA) was carried out for the PIM project. The PIM plan would consist of: an intake basin, pre-treatment, an infiltration system, soil passage, with recovery via enclosed abstraction techniques (drains/wells), and post-treatment. Several key actions and licences were required for the realisation of PIM. They started in 1990 and the total process took approximately a decade. Major preparatory actions (EIA Report, Communication with the community, purchase of land, two infiltration tests, several licenses for building treatment and pipe systems) were completed and even the definitive designs and specifications were made, but the project was never realized. The River Act licence for raising embankment was granted but later, in the second half of the 1990s, it was revoked.

WML: the preparatory work for the realisation of the surface water abstraction at Heel began in the first half of the 1990s. Approximately six years were assigned to the preparations, which included, for example, selecting a system, organising an EIA and applying for the licences. Research was conducted into the removal of microbes in the case of relatively short travel times during soil passage. The results showed that, for the conditions in Heel, 30 days was sufficient to meet the Drinking Water Act's requirements. The Heel project involved about 175 different licences, (e.g. production, abstraction, discharge and environmental licences). In the process of arranging and applying for licences, great attention was paid to collaborating with the licensing authorities. For instance, in organising the zone in an open manner, the abstraction activities could be combined with recreational ones. Thanks to good preparation and the involvement of the authorities, not a single licensing procedure underwent any delay. In 1998, the construction of the treatment system and the installation of the wells got under way; it was completed in 2001-2002.

Stabilisation

At this point the two projects of Brabant Water and WML diverge. At WML the entire transition has been gone through, and a new stable situation has been created, in which the company is using both groundwater and surface water as its sources. Brabant Water, in turn, is experiencing a so-called backlash: the transition has not been pushed through and the company still uses only groundwater as its drinking water source.

Brabant Water: the River Act licence was revoked. This meant that an intake basin, which was an inextricable part of the plan, could not be used. Without the intake basin, the plan had to be re-examined, particularly the pre-treatment. The decision as to whether or not to proceed with PIM was postponed. In the meantime, it became clear that drinking water consumption was stabilising and even declining. Since it became clear that there was enough room within the existing groundwater abstraction licences, Brabant Water began by designing a modular PIM and, at a later stage, effectively stopped the project. Following 2001, a number of abstraction reallocations were carried out with a view to further optimising water supply. These reallocations concerned the quality, costs and sustainability adaptations of the abstraction points.

WML: WML knows that it needs surface water because there is not enough deep groundwater (the preferred raw water) available. Because of economic reasons, there is a preference for groundwater. Also, Heel appears to be more costly because both the number of surface water intake stoppages (because of water quality reasons) as well as their maximum duration have been much larger than anticipated. With respect to the environment, it is not clear whether the closure of specific groundwater abstraction points has contributed much to nature conservation.

Summary

The transition from ground water only to both ground and surface water took approximately 20 years, Figure 8. Looking at the system as a socio-technic system, in this transitions different management decisions can be compared. We see that for one of the companies the transition was completely achieved while for the other it ended in a backlash. The dynamics of the drivers can also be clearly identified. In the 1990s the expected increasing water demand played an important role in the decision making. Note that by the time that the transition in source water was achieved the expected demand increase was much smaller.

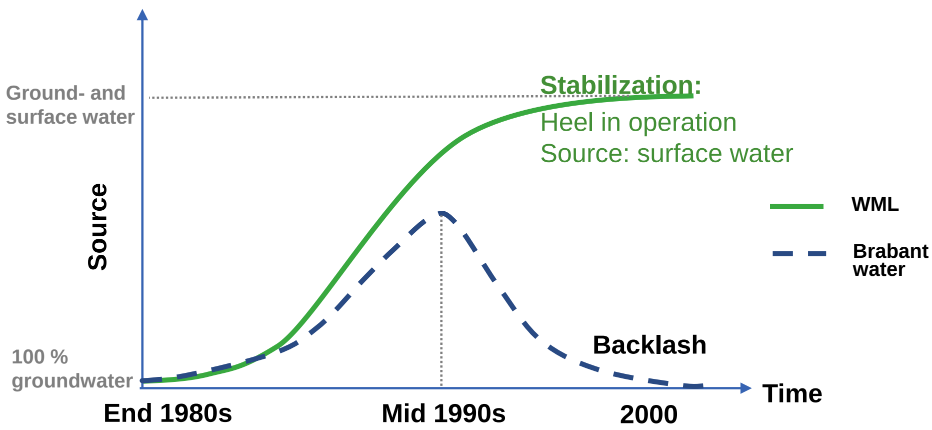


Figure 8 Schematic transition for the two water companies.

4.2.3 Treatment: towards a chlorine free production and distribution

Predevelopment

Around 1910, direct surface water treatment commonly comprised of sedimentation and slow sand filtration. In order to meet the growing water demand, rapid sand filtration was introduced prior to slow sand filtration and later, coagulation and flocculation were applied to reduce the load of the rapid sand filtration. The continuous increase of the water demand limited the application of slow sand filtration and it was more and more replaced by chemical disinfection (breakpoint chlorination). In many places in the world, chlorine is used in drinking water treatment and distribution systems. An advantage is that it is a low cost disinfectant and it is easy to control. Chlorine can be applied for several purposes, such as transport or breakpoint chlorination, iron oxidation or post-chlorination.

The first known application of chlorine in drinking water treatment is in Belgium in 1902, breakpoint chlorination was introduced in drinking water treatment in 1939 for ammonia removal purposes. The estimated annual chlorine usage in the Netherlands increases between 1950 – 1970 because of the increased use of surface water for drinking water production. By the 1970s chlorine use was common in the Netherlands for surface water treatment (about one third of the total water production).

In 1974, it was discovered that disinfection byproducts such as trihalomethanes (THM) are formed during chlorination. Some of these byproducts cause toxicological and mutagenic effects. In the Netherlands, discovery of THM led to a strong joint effort of the drinking water companies and KIWA (now KWR) to investigate the possibilities to reduce the formation of these harmful byproducts.

Take off

Important arguments for the use of a disinfectant residual are that the presence of a residual reduces the risk of microbial contamination, and the presence of a residual inhibits the growth of micro-organisms in the network. Some of the important drawbacks of chlorine usage are the formation of harmful disinfection byproducts, taste and odor complaints. Also, chlorine is less effective as a disinfectant against some relevant microorganisms such as parasitic protozoa.

In the Netherlands, the discovery of THM led to a strong joint effort of the drinking water companies and Kiwa (nowadays called KWR) to investigate the possibilities to reduce the formation of these harmful byproducts. That research comprised of investigating the use of minimal chlorine dosing, health effects of THM, the THM formation processes and control measures, alternative technologies for chlorine addition.

Some of the recommendations based on this research were implemented quickly and successfully. This led to a decrease of the chlorine usage of 40% within three years. The number of chlorine applications was not yet reduced. This initial improvement was realized due to the adaptation of the chlorine dosing conditions in transport chlorination (chlorination was limited to the summer period, with a reduced dosage), limiting breakpoint chlorine usage by closely monitoring the actual breakpoint curve and the reduction of iron oxidizing chlorine usage. The sharp decrease of the chlorine usage between 1971 – 1974 (Figure 9), is ascribed to the changes occurring at one specific facility. During these years, this facility changed both its surface water source as well as the technology for iron oxidation.

Acceleration

The research efforts regarding chlorine usage continued in the beginning of the 1980s, and lead to a further reduction of chlorination usage. Facility investments and optimizations have contributed to the overall chlorine reduction through further reduction of process chlorination and iron oxidation, the introduction of biologically active filtration and biological ammonia removal (replacement of chlorination with sand filtration) and the replacement of chlorination with micro-sieve filtration or activated carbon filtration. For the final two facilities that did not meet the sum of THM criterion, the breakpoint chlorination was replaced with advanced oxidation and UV disinfection processes in 2004 en 2005. The chlorine usage shows an increase in the 1980s due the start-up of a newly built pretreatment facility, this facility also causes the peak shown in 1990.

The post-chlorination was practically left unaffected in the initial effort in the 1970s for chlorine reduction. The efforts of the chlorine reduction in the water treatment led to lower concentrations of disinfection byproducts, but it was discovered that this positive effect was partly erased due to the strong amount of disinfection byproduct formation during distribution. Therefore, the research continued focusing on post-chlorination. In 1983, the water company of Amsterdam stopped its post chlorination and some others followed. Currently, a few facilities still use a small dose of chlorinedioxide as polishing step in treatment.

Stabilisation

Nowadays the application of chlorine in the Netherlands is limited to a minimum amount (as chlorinedioxide). The important conditions for distributing drinking water without disinfectant residual are met: usage of the best available source, a multi-barrier treatment, production of biological stable water, good engineering practices to prevent water ingress, and strict procedures for hygiene during mains construction and repair.

Summary

Several drivers can be identified for the transition. Complaints about taste and odor due to the application of chlorine have been recurrent over time. Between 1940 – 1960 this subject attracted much attention resulting in research and the application of different types of chlorine containing disinfectants. However, after the discovery of THM we find that human health is the main driver behind the described transition. Within the period of concern, the Drinking Water Decree was revised twice. Legal standards and guideline values on byproducts were formulated, and contributed as a driver for further reduction of the chlorine consumption. Safety issues of chlorine production and handling as well as the pollution occurring in the production process of chlorine can be considered to be (small) drivers. Due to the introduction of additional technologies, the multi barrier concept steadily grew. So, another driver is the improvement, availability and feasibility of alternative technologies. Of course, the discovery of the disinfection byproducts boosted the search of such alternative technologies. Figure 9 shows the development of the annual usage of chlorine products (left axis) and the development of the number of chlorine dosing applications (on the right axis).

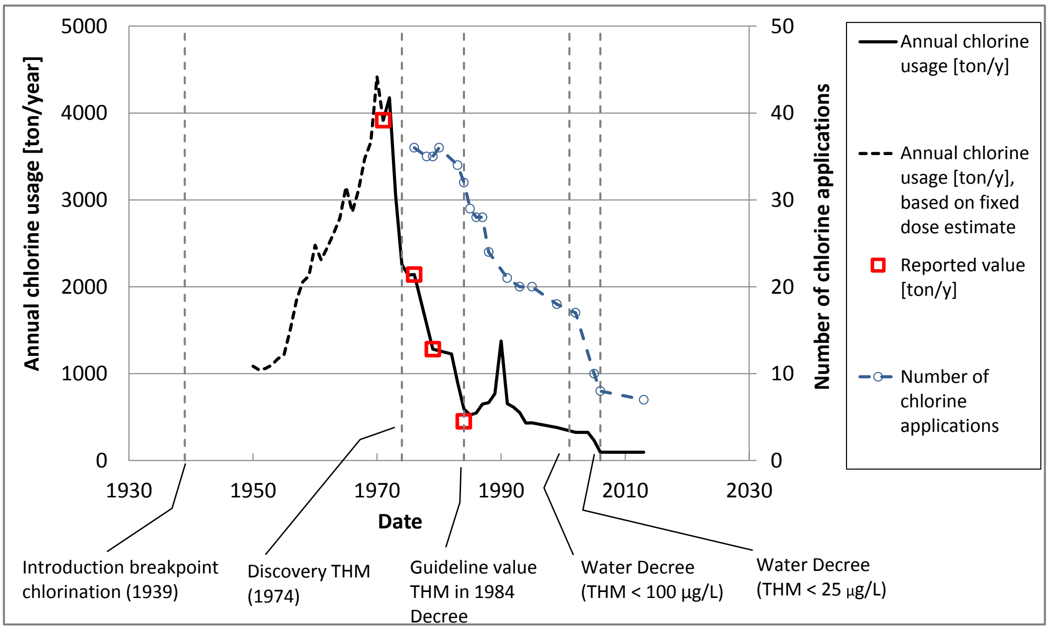


FIGURE 9 INDICATION OF THE HISTORICAL CHLORINE USAGE IN DUTCH DRINKING WATER PRODUCTION FOR THE PERIOD BETWEEN 1950 AND PRESENT. 'REPORTED VALUES' (MARKED □) ARE BASED ON DATA AVAILABLE FROM LITERATURE. 'ANNUAL CHLORINE USAGE' (SOLID LINE) IS A COMPOSED ESTIMATION BASED ON DIFFERENT SOURCES. 'ANNUAL CHLORINE USAGE, BASED ON FIXED DOSE ESTIMATE' (DOTTED LINE) IS AN ESTIMATION BASED ON THE ANNUAL USAGE OF SURFACE WATER FOR DRINKING WATER PRODUCTION AND A CHLORINE DOSAGE OF 13 MG/L FOR ALL SURFACE WATER TREATED. 'NUMBER OF CHLORINE APPLICATIONS' (DOTTED LINE WITH O-MARKERS) IS ON THE RIGHT AXES.

4.2.4 Drinking water installation: guidelines for the design of drinking water and hot water installations

Predevelopment

Despite all the changes in appliances and increasing hot water use, described in § 4.2.5, Dutch guidelines on the design of drinking water installations for non-residential buildings were, until recently, based on measurements carried out between 1976 and 1980 and there were no guidelines for predicting hot water use. As a result, suppliers of heating systems use company specific guidelines. In 2002, the old approach was no longer deemed suitable for the current situation due to the increasing range of available appliances in the market and to the changes in people's behaviour. In general, old guidelines overestimated the peak demand values. These peak values are crucial for the optimal design of the water system. Old designed systems are not only less efficient and therefore more expensive, but can also cause stagnant water, possibly leading to increasing health risks.

In the late 1970s, it was found that the "new" dangerous Legionella bacteria could grow in warm water. It was only after 1999, after a catastrophic outbreak, that strict regulations for Legionella prevention in drinking water were introduced in the Netherlands. Audits by water companies made clear that a lot of drinking water installations were not safe enough. The need for safe and reliable (hot) water systems was recognized, giving a boost to the development of new insights into the design and implementation of hot water installations. In 2001, guidelines for drinking water installation for buildings ISSO-55 were published, in which (hot) water use was still based on old measurements and calculation methods.

Take off

Understanding hot water demand is essential to select the correct type of water heater as well as the design capacity of the hot water device. For a proper design of (hot) water systems, the instantaneous peak flow and the hot water use in several time steps need to be determined. A reliable estimation of these values for an arbitrary building (type and size) by on-site measuring would require an intensive and expensive measuring campaign and would consume a lot of time. Therefore, in 2003, the water companies and the installation sector (TVVL / Uneto - VNI) commissioned KWR Watercycle Research Institute to investigate the possibilities of modelling (hot) water demand patterns

In the late 2000s, KWR developed a software tool to simulate cold and hot water use patterns called SIMDEUM. It is a stochastic model based on statistical information of water appliances and users. SIMDEUM models water use based on people's behaviour, taking into account the differences in installation and water-using appliances. This means that in each building, whether it is residential or non-residential, the characteristics of the present water-using appliances and taps (i.e. flow rate, duration of use, frequency of use and the desired temperature) are considered as well as the water-using behaviour of the users who are present (i.e. presence, time of use, frequency of use). With this tool, customize calculation of the peaks required for an optimal design of water installations was possible.

Acceleration

In 2010, the installation sector asked KWR to derive "design-demand equations" for the peak demand values of both cold and hot water for various types of non-residential buildings (office, hotel, nursing homes), using SIMDEUM. Then the new design rules were validated, in a two-step approach. The first step focused on validating the assumptions of how to standardize the buildings (the appliances and users). This was done with measurements and surveys. Cold and hot water diurnal demand patterns were measured (per second) for three categories of small-scale non-residential buildings. The surveys gave information on the number and characteristics of users and appliances, and on the behaviour of the users, like the frequency of toilet use, or the use of the coffee machine. Comparison of the simulated water demand patterns with the measured patterns showed a good correlation. The results showed that the basis of the design-demand equations, the standardised buildings in SIMDEUM, is solid. The second step focused on validating the design-demand equations by comparing the simulated and measured peak flows. The results were very good. Also, the studies showed that the old guidelines overestimated the maximum instantaneous peak flow for both cold (e.g. 70%-170% for hotels) and hot water.

Next, the consequences for design of the drinking water installation and heating system were assessed. The new equations lead to a better estimation of the maximum instantaneous peak flow than the old guidelines. The new equations reduce the design of heater capacity with a factor 2 to 4 compared to suppliers proposals, while still meeting the desired need and comfort. Thus, the improved insight of the new design-demand equations will lead to an energy efficient choice of the hot water systems, and thus save energy. Also, the smaller design of the heating system reduces the stagnancy of water, which may lead to less hygienic problems.

Stabilisation

With a 10 year study, more insight into the actual (hot) water consumption was gained. Simulating the water demand patterns with SIMDEUM showed to be a reliable method to predict water peaks and daily water patterns, leading to an update in the guidelines for the design of drinking water installations and hot water systems in non-residential and multi-residential buildings (ISSO-55. 2013). The guidelines for the design of drinking water distribution systems also refers to these guidelines. The revision of the guidelines will lead to smaller systems than the ones used in practice and the ones predicted by the old guidelines.

Summary

Guidelines are enforced when there is a need for them. Guidelines are based on state-of-the-art knowledge. For instance, hot water guidelines were needed due to 1) increase gas use and fast adoption of showers, 2) new buildings and new water connections, 3) laws and regulations regarding safety. Due to the changes in the (hot)water use and routines, these guidelines became obsolete. Guidelines are adapted when 1) calamities happen (e.g. legionella outbreak), 2) new requirements have to be met (sustainability/energy efficiency) and 3) new knowledge is developed, for instance measurements showing that the old guidelines are overestimating demands or the development of SIMDEUM. Nowadays new knowledge is based on research, possibly as a result of calamities or new requirements.

Figure 10 shows an overview of the use of guidelines for the design of water systems in the Netherlands for residential and non-residential buildings.

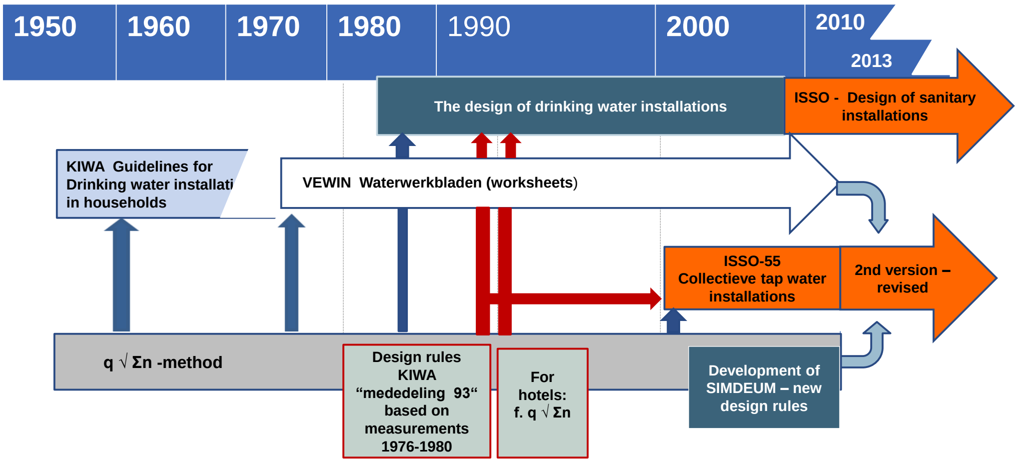


FIGURE 10 OVERVIEW OF AVAILABLE METHODS AND GUIDELINES IN THE NETHERLANDS.

4.2.5 Customer's tap: change in drinking water demand

Predevelopment

In 1901, with the Dutch Housing Act, installation of a toilet in each household became compulsory. Showers started to be installed in the 1930s. However, introduction of showers was limited due to lack of hot water supply. In 1933, a compulsory installation of warm water would be unaffordable for most. The shower was first mentioned in a national guideline in 1940, where it was stated that bathing was a necessary provision in the home and a bathroom should have at least 1.5 m² with a shower or bath and a sink. Hot water was needed to encourage the residents to bathe but high prices were still a barrier. The majority of households did not feel the urgency to adapt to the new technology and kept using cold water only. The Housing Census of 1956 reported that nearly 30% of the households - 750,000 - had a separate bath or shower. However, the majority of the population took a shower or a bath in public baths.

Take off

By 1951, 82.4% of the population was connected to piped water, mainly in urbanised areas. In some cities, housing corporations and energy companies took action to accelerate the market penetration of gas appliances. For instance, in Maastricht, the municipal gas company came in the 1950s with a new, attractive hire and purchase (lease) scheme for geysers. The gas company could purchase and finance the installation of a geyser, including faucets and showerheads, and the tenant would pay back the costs in sixty monthly instalments to the gas company. In the 1950's, some intermediary organizations were founded to assist consumers: The Dutch household council and the Consumer association. These organizations provided independent and objective advice and information to the people, playing an important role in the transition towards modern households. In 1954, a cost comparison (instigated by the Dutch association of housewives) showed that washing clothes at home was comparable to the costs in a central laundry facility, thus giving a boost to washing machines in the homes.

In 1957 the Drinking Water Law was enacted by the Dutch government. This was the beginning of the involvement of the Dutch government and the EU in laws and regulation concerning the drinking water supply.

Acceleration

In the 1960s, a period characterized by rapid growth, prosperity and social changes began, driven by the discovery of large quantities of natural gas in Groningen. The decision to use gas for heating of buildings brought the desired comfort. Almost all Dutch households started to use natural gas within a few years. In 1968, 78% of homes had a gas connection. The natural gas coverage rose rapidly to 89% in 1975 and further to 97% in 1980. Not only the number of connections, but also the average annual use per home rose largely. The main reasons for this was the increasing use of gas for stoves and central heating and the increasing use of warm water for shower and bath.

Consumers' need for comfort and luxury also grew. Low gas prices enabled the acceleration on the adoption of domestic water heaters. This led to an important change: in the mid-1960s, warm water was no longer seen as luxurious. And by 1970, adoption of showers reached 75% and 97% of the new houses had warm water and a shower or a bath. Adoption of showers implied changes in routines, this is seen by the "lock-in" of the adoption of bathtubs. The 1970's and 1980's witness an accelerated diffusion of use of water consuming appliances. Daily water consumption per person grew from 80 litre per capita per day in 1960 to 108 in 1980, a 35% increment in two decades.

The price of natural gas price for households rose sharply between the early 1970s and 1985 – the first energy crisis. During this period the real price increased (taking inflation into account) with 135%. The average household gas consumption for heating decreased significantly in 1990 due to better insulated buildings and more efficient heating systems. However, energy consumption for hot water supply did not decline since the energy crisis of 1973. On the one hand, the bathing frequency increase slowed down in the 1970s and many households installed a water-saving shower head. On the other hand, people nowadays take a shower or bath more often than in the 1970s as a result of increased standards of personal hygiene.

Stabilisation

The residential water consumption had a peak in 1995, and since then a slow downward trend in per capita household water consumption took place. In 1991 the third 10 year plan of the government was established which led to increased household water costs. To slow down the increasing water use, Vewin started the campaign "Be wise with water" and to slow down the increasing hot water use, the *National Consultation Platform for Hot Water* was formed. In 1995 the government, water companies, energy companies and other relevant market parties signed a cooperation declaration *Approach for Hot Water Conservation*. In 1997 European legislation made energy labelling mandatory for washing machines, and for dish washers in 1999, which specifies the energy and water consumption of an appliance and grades overall energy performance. As a consequence, the average consumption per washing load of washing machines is almost halved starting from 100 litres in 1992 to 50 litres in 2010. Furthermore, new European norms of sanitary fixtures were developed that take specific water consumption into account, e.g. NEN-EN 1112 of 1997.

Summary

In the Netherlands, the availability of energy (gas) was a main driver behind the increase of the per capita water demand. Gas availability influenced changes in the regime at first by increasing standards of comfort and in the long run by influencing building codes. Energy efficiency has been a constant driver in the last two decades, as shown in the transition towards more energy-efficient systems to heat water, also for heating tap water. This transition has been supported by technological developments while comfort and user behaviour were not affected. Figure 11 shows the residential water consumption per capita since 1960.

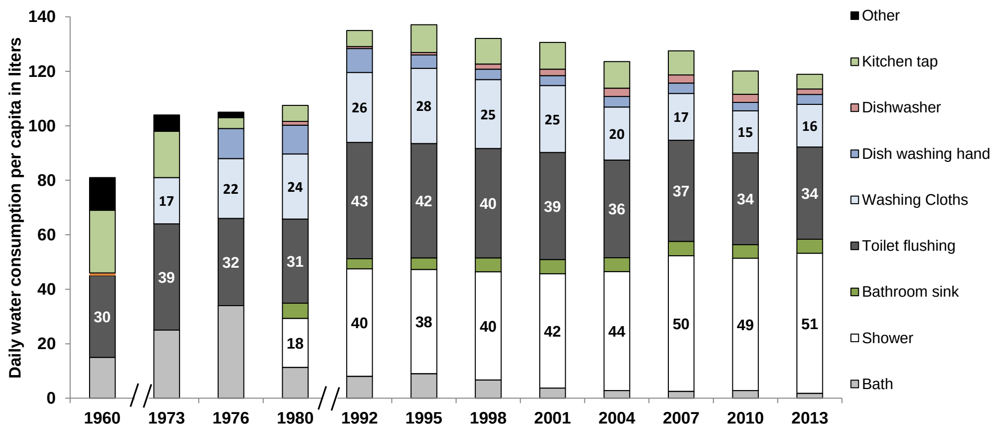


Figure 11 Residential water consumption per capita since 1960 (Source vewin surveys)

4.3 Conclusions & steering possibilities

4.3.1 Extent of adoption

The examples of transitions that we studied showed a wide variety of end results. Full penetration, lock in and stabilization (see Figure 6 and Figure 7) were all found.

The transition to chlorine free drinking water production and distribution was developed to almost 100 % penetration; the transition in water demands showed for households a 100 % penetration for a shower and a "lock-in" of a 50% penetration of a water saving shower head; the transition towards an alternative raw water source stabilized for WML (using both the existing ground water sources and the newly developed extraction of surface water) and a back lash for Brabant Water (where surface water was in the end not adopted for drinking water production). The transition in guidelines in household appliance installation practices in still ongoing. A change is noticeable in the design of the installation from the craft of the plumber towards a model and water quality based design. The guidelines have been adopted, but not all consultants have implemented the new approach yet.

4.3.2 Rate of change

The examples of transitions that we studied all showed more or less the same rate of change; the transitions all typically took 20 to 30 years.

The full adoption of the new water source of WML took 20 years, the study and then backlash for Brabant Water also took ca. 20 years. Although the last 20 years the per capita water use has hardly changed, there has been a change within the residential water demand. There was a change in penetration rate of more water using appliances, then a change in the more water efficient versions of these and a more efficient behaviour (less bathing, more showering). Typically these changes took about 20 years to reach the stabilization phase, the acceleration phase takes about 10 years. The chlorine reduction was first established by reduction in (optimisation of) existing treatment plants; after that by introducing new treatment technologies. The total transition took ca. 30 years.

4.3.3 Drivers of change and steering possibilities

The cases showed that it is important to understand the components in the transition in order to understand the extend of the adoption and the rate of change. Also, this gives some insight into the sphere of influence and especially into the transactional zone.

The transition towards a chlorine free distribution was fully driven by the internal system, i.e. the Dutch drinking water sector. The health problem caused by disinfection by-products was first raised by an employee of a drinking water company, then the problem was further studied and a technological solution was investigated, paid for by the Dutch drinking water sector. The change of legislation was strongly influenced by the drinking water companies.

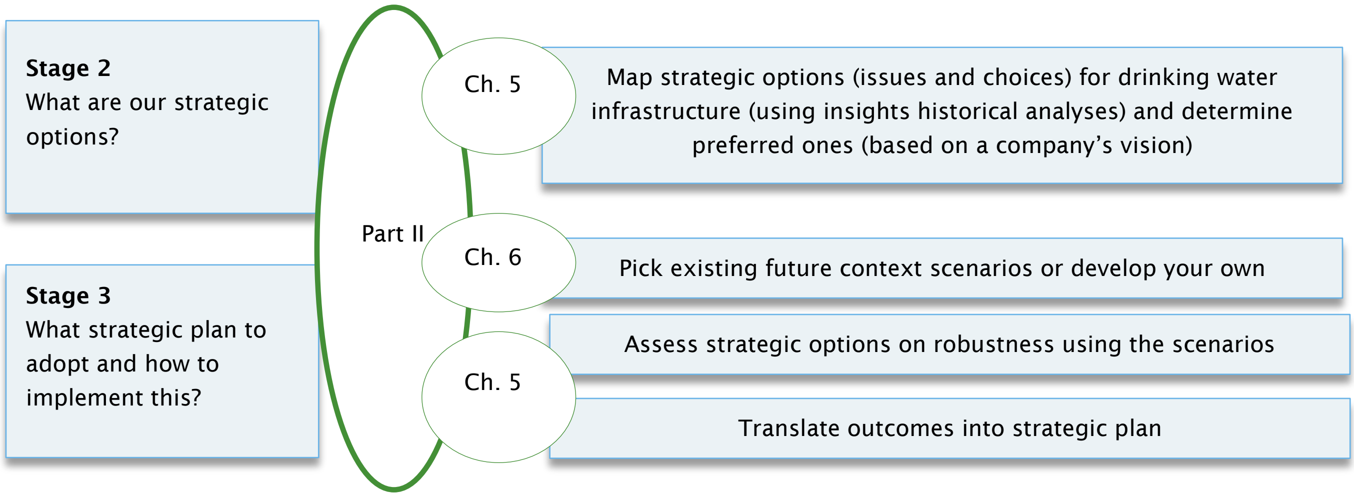
The transition (or not) towards a second source for drinking water was driven by the external system (expected increase of drinking water demand, expected environmental legalisation influencing water quality) and with respect to the rate of change by the internal system (the two drinking water companies determined how fast studies were done and when permits were requested). Also, there was a great need for the transactional zone with respect to accelerating the transition (cooperation for spatial planning, and extraction permits) or changing the transition towards a backlash (not pursuing legal requirements).

The changes in per capita water demand were driven mainly by the external system; the drinking water companies hardly tried to influence this. The energy availability had the largest influence on per capita demand; first the access to gas in every house led to the increase in showers, then the gas price and environmentally driven desire to save energy led to more efficient hot water appliances such as showers, washing machines and dish washers. EU regulation had an influence on water efficient toilets as well. With the changes in water demand and the increasing of cost of measuring the transitions, a need for a more model based approach of understanding water demand came up. As we see that after the pure need for water availability, there is a change in drivers for water demand in both quantity and quality aspects (e.g. individual demands for comfort as people are used to unlimited availability led to more luxury showers that are being installed; awareness of limited resources drives people to save energy and water; economic incentives may affect water use; health awareness causes more focus on water quality), there is a need for more justification of the design of the drinking water installation and distribution network. Here, the internal system is more than just the drinking water companies; it also entails the installation sector.

Part II

Visualizing and planning for futures of drinking water infrastructures

Part II looks at stages 2 and 3 of the framework, which will be described in chapters 5 and 6



The following questions are addressed:

	In the strategic planning process	Read chapter	How to design a strategic planning process
...how to deal with the future in strategic planning of drinking water infrastructure?	In the realisation of strategic plans	4, 5	How to cope with (key) uncertainties and how to monitor these
	In a specific case study of a Dutch water company	5	Inspiring / telling example
...what future scenarios are, how they can be used in strategic planning processes and generic, ready-made scenarios	Building your own future scenarios	5	Process of and tools for building scenarios
	Enriching the generic, ready-made scenarios	6.2	How to make the generic, ready-made scenarios specific for one's own operating context
	Applying the generic, ready-made future scenarios	6.1	How to use the generic, ready-made future in one's own strategic process

5 Strategic planning of drinking water infrastructure: assumptions, techniques and outcomes

This chapter describes the process and potential outcomes of strategic planning processes for drinking water infrastructure. As strategic planning is inherently bound up with the future, assumptions on how to perceive of, and how to deal with, the future are essential. The first section of this chapter makes those assumptions explicit. Strategic planning is furthermore carried out using certain techniques, some of which are provided in this chapter in subsequent sections. In particular, the chapter outlines how strategic questions and options may be identified, how future scenarios may be developed and how those options can be assessed on robustness using such future scenarios. Outputs that are generated by this process for water companies in the Netherlands are discussed in the last section.

5.1 Assumptions: Exploring future presents in strategic planning processes

Chapter 1 briefly outlined some key assumptions underpinning the study of futures. This section will elaborate on these, given their important implications for both the process and results of strategic planning. The previous part of the book showed that past and present (social and technological) developments create conditions that partly shape future ones. This is obvious in the case of physical drinking water infrastructure. For instance, the building of an urban water supply network over time enables *and* constraints subsequent developments in cities; it allows for the city to flourish and expand, but it also provides limitations, say for entirely different water supply systems that require another logic and very different (politico-juridical) rules of the game in order to function well. It indicates that the future is not entirely 'open', that new beginnings are an illusion and that (implicitly) taking on an a-historical view can have serious future implications when it comes to investing in drinking water infrastructure.

But equally problematic to disregarding historical analyses is discounting or 'commodifying' the future: seeing the future as an empty 'hole' that is ours to fill, driven (solely) by *present* interests. Still, this is how the future has come to be increasingly seen in contemporary industrialized countries (Adam and Groves, 2007). This perspective of the future has serious time-space implications. It pretends the future itself is devoid of context and people, and assumes the future can be calculated, predicted and 'traded'. Our actions in the present are primarily driven by short term gains, many of which lay a claim on the (long-term) future, without explicitly considering and hence, taking responsibility for, the implications on the socio-material dimensions of that future. Practices, instruments and products in the financial sector comprise a prime and very explicit example hereof. Many of these are driven by *immediate* or *short-term* gains and based on some *assumed* future state, like in the case of subprime mortgage markets and derivatives. But the financial sector by no means stand alone in this and short term, self-interest has become a notable driver for many an actor's actions in the present. Approaches whereby the future is predicted, transformed and controlled for the benefit of today is what Adam and Groves (2007) call the "present future".

In contrast, what needs to be explored in strategic planning processes are so-called 'future presents' and 'futures in the making'. The 'future present' stands for a position that allows us to account for historically shaped conditions and processes, upon which to build further, whilst explicitly acknowledging the possible effects of these and our present actions on the future and future social and environmental well-being. 'Futures in the making' point at actions already set in motion, without having transferred into tangible outcomes yet. Crucial in these concepts is taking responsibility for potential effects of our present actions on places and generations in the future. This can only be done by contemplating the future vis-à-vis our present will, and by taking seriously historical processes. The starting points deriving from these assumptions are to explore:

- not one, but various possible futures
- how present desires regarding drinking water infrastructure fit in these futures
- In relation to historical drivers and patterns studied earlier, robust alternatives to present strategies of creating and using drinking water infrastructure.

Making all this clear and explicit helps actors “taking responsibility for the time-space distantiated effects of their (in)actions” (Adam and Groves, 2007).

5.2 Scenario planning for developing strategic plans

Building on the abovementioned assumptions, a suitable method with which to develop strategic plans for drinking water infrastructure is called scenario planning (Nekkers, 2006). Given that the long-term future is characterized by high levels of uncertainty and low levels of determinacy (see Figure 12), exploring how preferred strategic options may hold in the future is done by the use of future scenarios rather than by predicting the future or forecasting the most plausible one.

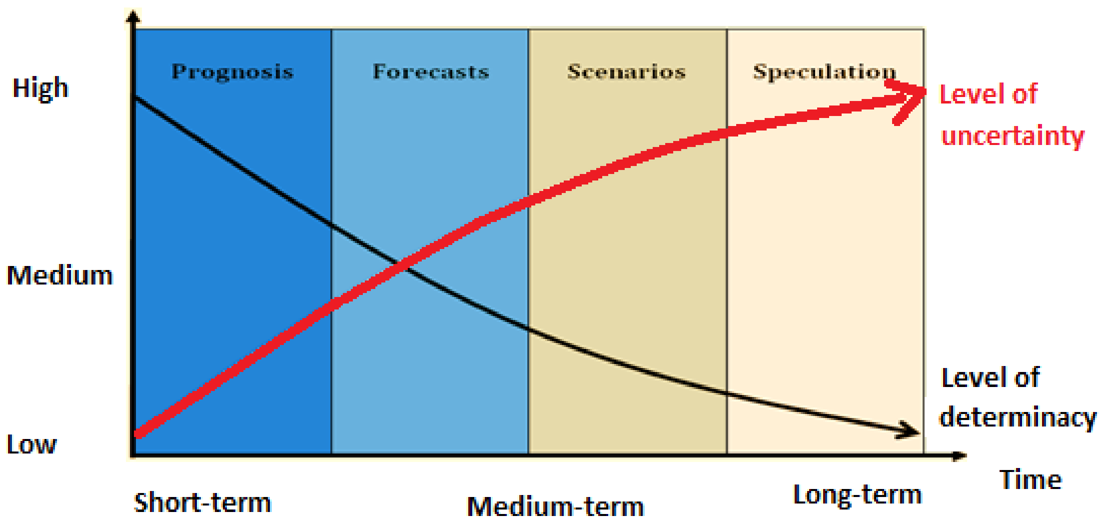


FIGURE 12 TIME, UNCERTAINTY AND WAYS OF STUDYING THE FUTURE (AFTER NEKKERS, 2006: 66)

Scenario planning steps are those that are listed under stages 2 and 3 in the approach adopted in this book. There are three steps:

1. Mapping strategic questions and options for drinking water infrastructure (using insights from the historical analyses) and determine preferred ones (based on a company’s vision)
2. Pick existing future context scenarios or develop your own
3. Assess strategic options on robustness using the scenarios

These steps adhere to different spheres of influence (see Figure 3). In the first step, those options are mapped where water companies have full or partial control over, thus related to their internal and transactional systems. The second step on future scenarios deals entirely with the external environment; plausible external trends and conditions are integrated in (usually four) future scenarios. In the third step the previous two steps and spheres of influence are linked, i.e. this involves the assessment of 'controlled' options in possible environments one has no control over. This is visualized in Figure 13.

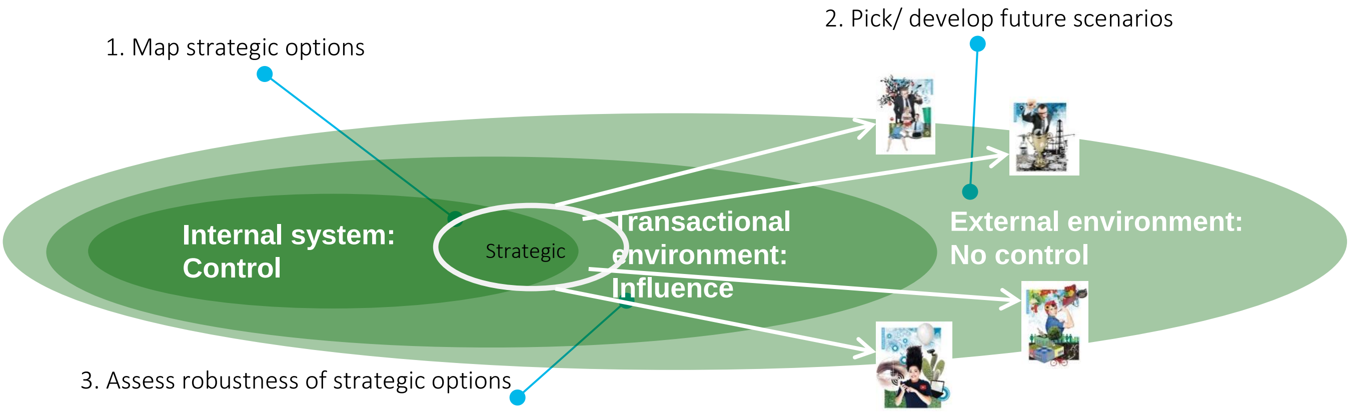


FIGURE 13 SCENARIO PLANNING STEPS IN THE DIFFERENT SPHERES OF INFLUENCE

These steps will be further explained below, illustrated by experience and outcomes from the implementation of these steps in the project that led to this book and in the water company Dunea.

5.3 Mapping strategic options

An important step in the strategic planning process is identifying and determining the most relevant strategic questions and options regarding water infrastructure. Important in this step is to focus on those strategic fields you (think you) have full control over (internal system) or those which can reasonably be influenced (transactional environment), for instance by working together with stakeholders or by lobbying. Also relevant when doing this for water infrastructure is to recall that there are both social and technological aspects related to the strategic questions and options. This step is greatly facilitated with insights gained from historical studies into (parts of) the water infrastructure system, for instance when it comes to influential drivers behind the development of (parts of) the water infrastructure, the extent to which infrastructure is 'path-dependent' or the ways in which decision-making on water infrastructure takes place.

This step has been carried out in a workshop with asset managers and water infrastructure specialists from all Dutch drinking water companies. Their task was to tackle the following:

What are the most relevant strategic questions regarding drinking water infrastructure for the coming five years, with potentially far-reaching effects on the long-term (i.e. time horizon of 2050)?

They were asked to write down all strategic questions that came up in a brainstorm, related to all parts of drinking water infrastructure, such as sources, treatment, distribution as well as the customer. Each strategic question was then specified by identifying different strategic options. In the workshop, two (and in one case, three) options were identified for each strategic question, but this need not necessarily be confined to two options only; there are more alternatives to think of, and all alternatives could be assessed in the third step of the strategic planning process. These combinations of strategic questions and options were then prioritized in terms of their uncertainty, impact and urgency. Out of this emerged eight strategic questions and options deemed the most relevant ones by the group of asset managers. These questions and options are listed in Table 5.

TABLE 5 TOP EIGHT RANKING OF STRATEGIC QUESTIONS AND OPTIONS REGARDING DUTCH DRINKING WATER INFRASTRUCTURE

Strategic questions/ dilemma's regarding drinking water infrastructure	Strategic options*
What treatment units will we build the coming five years?	**A:** Modular, flexible, decentralized **B:** Full-scale, fixed, centralized
How will we operate in the underground the coming five years?	**A:** Alone, driven by own vision and perspective **B:** With other asset owners, driven by a collective vision
How will we identify and assess asset risks the coming five years?	**A:** Proactive (identifying risks and assess whether these can be mitigated or tackled with available means (time, budget, personnel)) **B:** Reactive (intervene after clear risks occur)
What is the margin on top of the predicted capacity, based on which we design and utilize assets the coming five years?	**A:** As usual (5% marge) **B:** Different (3% or less)
How will we organize the supply of water without surprises for customers the coming five years?	**A:** Emphasis on the reduction of time that customers are without water by investing in physical assets **B:** Emphasis on prevention of or adaptation to potential surprises by (communicative) interaction with customers
How will we achieve the greatest degree of comfort for customers (e.g. related to water hardness) the coming five years?	A: By focusing on costs B: By focusing on water quality C: By focusing on costumer services
How will we cope with the result of potential reduced demand of drinking water the coming five years?	A: Shedding sources B: Reduce pipe diameter (to prevent long residence time)
Will we remain focused on drinking water only or will we extent our focus the coming five years?	A: Focus limited to drinking water B: Extended focus towards water cycle (or even multi-utility) company

A final important part of this step involves determining for each strategic question which of the strategic options are most worth pursuing. This is a question of will, i.e. what is deemed most desirable by the actor undergoing the strategic process, rather than what the actor think he *must* or *can* do. This is done by taking a company's identity and vision as starting points, asking which of the options identified are most in line with who you are and what you want to accomplish as an organization. Furthermore, in line with exploring 'future presents' (see paragraph 5.1), this is done by examining the potential ethical, social, environmental and other types of consequences of pursuing a strategic option.

5.4 Future scenarios: building your own or using existing ones

5.4.1 Process and techniques

There are different types of scenarios one can use, depending on one's goal. Börjeson *et al.* (2006) distinguish between three main categories of scenario planning: predictive, explorative and normative scenarios. Predictive scenarios are constructed in answer to the question what *will* happen, assuming the future can be known. Explorative scenarios tackle the question of what *can* happen, on the basis of a highly uncertain future that can be explored, but not known. Lastly, normative scenarios respond to the question of how an explicit normative target in the future can be reached, which require changes in prevailing systems/structures. Each of these categories are further subdivided into specific scenario types (see the typology depicted in Figure 14).

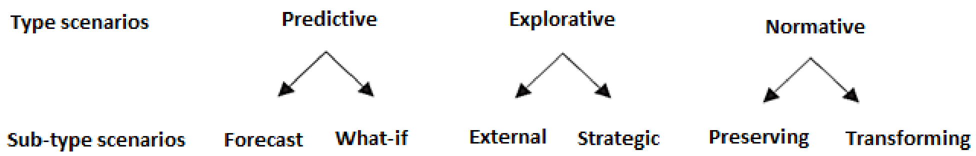


FIGURE 14 TYPOLOGY OF SCENARIO TYPES (AFTER BÖRJESON ET AL., 2005: 14)

The approach of this book uses explorative, external scenarios. External scenarios describe how external developments or 'the context', where one has no control over, develop over the long term. Building external scenarios typically involves a process of horizon scanning and identifying two key external developments that score high both on 'uncertainty' and 'impact' and of which scenario developers and users agree that these trends will remain highly influential for the decades to come. These two key uncertainties are then plotted on two axes yielding four distinct, but equally plausible future scenarios (Van 't Klooster & Van Asselt, 2006; see Figure 15).

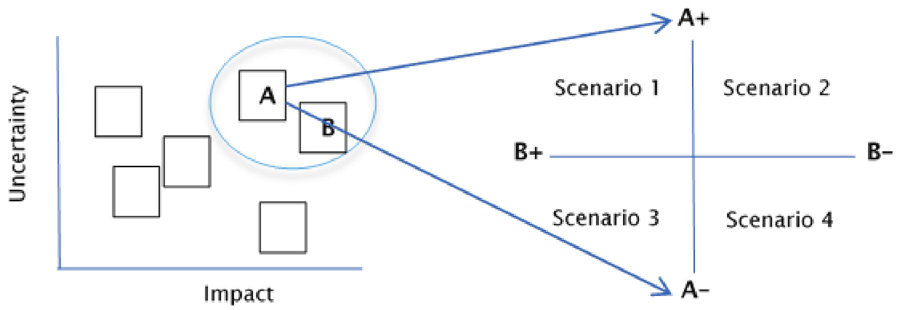


FIGURE 15 SCENARIO BUILDING PROCESS ALONG TWO AXES REPRESENTING KEY UNCERTAINTIES

Strategic planners have a choice to develop their own scenarios using such techniques. But this is a process that requires considerable resources (time, budget) that not every organisation has available or would like to spend. In that case, there are alternative options. Strategic planners could also pick and use existing scenarios and use those without any alteration, or they could pick existing ones and make those applicable to their own context before using them. There are national and international institutes producing external future scenarios, such as the Welfare, Prosperity and Quality of the Living Environment scenarios developed by the Netherlands Bureau for Economic Policy Analysis (CPB) and the Netherlands Environmental Assessment Agency (PBL) on the Dutch national level, or the related GEO5 scenarios made by the UNEP Global Environmental Outlook on a global scale. In the project that led to this book, four future scenarios have been developed specifically for water companies. These scenarios are ready-made and can directly be used in strategic planning processes, but they could also be made more specific for a water company's service area. These options and the scenarios are described below.

5.4.2 Four future scenarios

Four generic scenarios have been developed and used in a project for all ten drinking water companies in the Netherlands. Two highly uncertain driving forces with a large impact on drinking water companies and their infrastructure were chosen as the two axes in this project. These are:

A. The size and strength of local authorities
B. The prevailing societal structure that orients and steers actors.

Regarding axis 'A', it is assumed that in thirty years from now there will still be a public steering body that governs the city, which (re)produces and/or transforms structural conditions in that city. The extent to which these conditions shape socio-material developments and actors in the city varies however, depending on size and strength of this governing body. The axis thus becomes a strong/ decisive local government on the one end of the continuum versus a weak/ withdrawn government on the other.

Axis 'B' denotes a simplified dichotomy of the market and individual as the one major structure and orientation in the city vis-à-vis a dominant orientation on society and collectivism. The two axes together yield four future scenarios of the city, briefly titled the Collective City, the Self-sufficient City, the Competitive City and the Smart City. Each city has been characterized and described using 'uncertainty factors' such as dominant thinking, type of economy, ways of living, science and technology systems, etc. The two axes and the four scenarios are illustrated in Figure 16. The storylines of each scenario are described in detail in chapter 6.

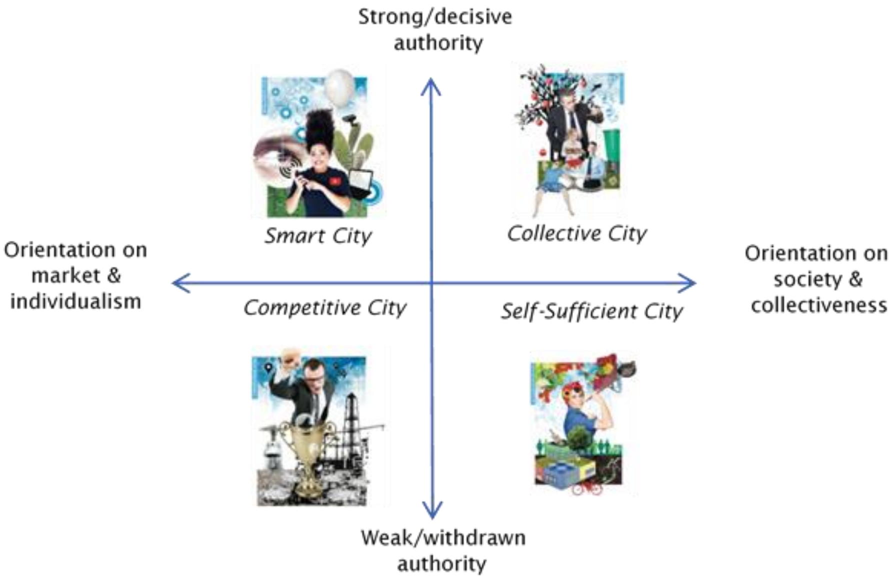


FIGURE 16 FOUR FUTURE SCENARIOS OF THE CITY

5.4.3 Enriching scenarios for the water sector

These generic scenarios were "enriched", i.e. made more connected to the water sector. That is, additional uncertainties in the external environment were identified and included in the above scenarios that may have significant consequences for future operations of water companies. The outcome are 'enriched scenarios' that describe in more detail the uncertainties for water companies. The use of such scenarios for the testing of strategic options enhances the reliability of the strategic planning process.

Enriching existing scenarios and make them more applicable to a specific context can be done in a workshop with an interdisciplinary group of participants. A variety in backgrounds and roles of participants is important, in order to identify important uncertainty factors over a range of social and technical dimensions. In our example project, the abovementioned scenarios were enriched for the water sector and therefore, a workshop was organized in which researchers from a water research institute and professionals from water companies participated. There were specialists in natural sciences including water technology and microbiology, as well as strategists and social scientists.

Five steps were followed to come up with the enriching uncertainty factors:

1. Identifying external trends and developments that would specifically impact on a water company's operation
2. Prioritizing the key uncertainty factors from all identified factors in step 1
3. Determining the scale or 'bandwidth' of each key uncertainty factor (see Figure 17 for the example of water quality; this can be ranged from 'high' to 'low' quality)
4. Embedding the key uncertainty factors in all four scenarios
5. Making scenarios internally consistent. This check is necessary for constructing a diverse set of scenarios with each having its own, distinctive path, whilst remaining plausible stories of how futures may look like.

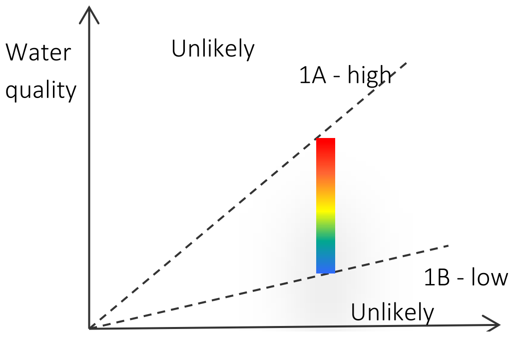


FIGURE 17 EXAMPLE OF UNCERTAINTY FACTORS IN THE EXTERNAL ENVIRONMENT: WATER QUALITY

The output of this workshop were the ten key uncertainty factors in the external environment and how they are embedded in the future scenarios, see table 5.2. It is assumed these factors will have considerable impact on the water sector's operation, but are out of the water company's sphere of influence; they cannot (or only to a limited extend) be controlled.

Water companies can go further still and enrich the future scenarios for the external environment of their specific service area. Dunea, a water company with its service area in the Randstad in the western part of the Netherlands, has done just that. In a strategic planning process for their organization, they have used the generic scenarios outlined above and made those specific for the Randstad. The next section will describe what it contributed to their process.

TABLE 6 KEY EXTERNAL UNCERTAINTY FACTORS INFLUENCING WATER SECTOR OPERATIONS AND THEIR MEANING IN THE SCENARIOS

Key external uncertainty factors	Scenario: Collective City	Scenario: Self-Sufficient City	Scenario: Competitive City	Scenario: Intelligent City
Trust in drinking water company	High (1)	Fairly high (2)	Low (4)	Fairly low (3)
Importance attributed to sustainability	Fairly high (2) –	High (1)	Low (4)	Fairly low (3)
Water demand	Low (4)	Fairly low (3)	Fairly high (2)	High (1)
Regulatory framework	Fairly stringent (2)	Fairly loose (3)	Loose (4)	Stringent (1)
Ownership water entity	Public	Public	Private	Private
Political stability	Stable (1)	Fairly weak (2)	weak (4)	Fairly stable (3)
Availability water	Abundance (1) –	Reasonable (2)	Scarcity (4)	Critical (3)
Availability resources other than water	Abundance (1) –	Reasonable (2)	Scarcity (4)	Critical (3)
Pressure on subsoil	Low (4)	Fairly high (2)	High (1)	Fairly low (3)
Climate change	KNMI/Gh (3)[6] –	KNMI/Gl (4)	KNMI/Wh (1)	KNMI/Wl (2)

5.4.4 Making scenarios applicable to individual water companies: the case of Dunea

The strategy of the water company Dunea is revised every five years. In their latest revision and strategic planning process, Dunea used the four future scenarios, but decided to adapt those to their specific external environment, the Randstad. They thus adopted the axes of the existing scenario framework and their main features, but enriched the scenarios with self-identified uncertainty factors relevant to the Randstad, in each of the PESTLE dimensions (Political, Economic, Social and demographic, Technological, Legislative, Ecological). Examples of trends identified in these dimensions include new models for financing public services, experiencing nature and combining nature reserves with a specific function, such as water extraction, the participation society and bottom-up initiatives and 'circular' and 'share' economies. The integration of these trends in the generic scenarios generated the Dunea-specific future scenarios, namely the Smart Randstad, the Collective Randstad, the Self-sufficient Randstad and the Competitive Randstad. The adapted illustrations of these scenarios are depicted in Figure 18

.

These scenarios played a key role in Dunea's strategic planning process, which eventually resulted in a new five-year strategic plan for the period 2015 – 2020. The scenarios were primarily used for assessing the robustness of strategic goals Dunea professionals had identified earlier. The value of the scenarios as a tool in the strategic planning process is that it provided a very structured and original way to discussing amongst colleagues what influential trends and developments are in the (future) environment Dunea operates in, and how to make sense of these. It helped Dunea deciding which trends and developments are and which are not relevant for their future operations. It is the integration of various types of trends and developments in four different, but all plausible

[6] KNMI is the Royal Netherlands Meteorological Institute and translates research results from the IPCC into climate scenarios for the Netherlands. The latest scenarios, developed in 2014, differ in the extent to which the global temperature increases ('moderate' and 'warm') and the possible change of the air circulation pattern ('low value' and 'high value') (KNMI, 2014, see http://www.climatescenarios.nl/ scenarios_summary/index.html). The four scenarios are Gh (moderate global temperature rise and high value change in air circulation pattern), Gl (moderate; low value), Wh (warm, high value) and Wl (warm, low value).

future scenarios that makes it particularly valuable; it makes that one does not attribute one scenario (or trend) a greater likelihood than others, a tendency often present in the analysis of trends and developments.

FIGURE 18 ENRICHING GENERIC TO CONTEXT-SPECIFIC FUTURE SCENARIOS FOR DUNEA

The scenarios were also used by Dunea for decision-making in a policy issue regarding fire hydrants in their service area. Professionals imagined what potential consequences for Dunea would be if the scenarios would come true. Here too, the scenarios helped professionals arriving at a shared view on how to position Dunea in this policy field. Thus, the scenarios are useful not only for strategic processes, but can help in decision-making in specific policy issues as well.

5.5 Assessing robustness of strategic options and translating into a strategic plan

In the third step in the strategic process, the outputs of the previous ones are confronted and how the identified strategic options hold under the four future scenarios is assessed. This too is a participatory activity and the outcome is an extensive weighing of options, giving direction to and building blocks for the ultimate strategic plan. In the project, this third step was carried out in a workshop with strategists from nearly all Dutch water companies.

This was the target group deemed most suitable for the workshop, as the exercise gains from familiarity and experience with both strategic planning methodologies and decision-making practices in the context of the Dutch water sector. The assessment of whether or not a strategic option is considered ‘robust’ followed from discussion and debate amongst these strategists. If one faces, for instance, the strategic question whether to choose between surface water and groundwater as (main) source for the production of drinking water, this strategic planning technique generates an outcome like that pictured in Table 7.

TABLE 7 FICTITIOUS EXAMPLE: TESTING ROBUSTNESS OF STRATEGIC OPTIONS OF USING GROUND- OR SURFACE WATER AS (MAIN) SOURCE IN EACH OF THE FUTURE SCENARIOS

Strategic Question	Strategic Option					Conclusion
Preferred source for producing drinking water	Groundwater	V Argument x	V	V	V	Robust, because …
	Surface water	V	X	X	V	Not robust, because …

With all strategic options assessed, what rests is the analysis and translation into concrete strategic steps and all steps together should form a coherent strategic plan. The translation from strategic building blocks into a strategic plan basically involves two types of actions:

1. If the preferred strategic option is considered robust in all future scenarios, it can be formally adopted as part of the overall strategic plan. Possibly specify the option for the foreseeable future, for instance in terms of what is to be accomplished, why (rationale), how and when, who is responsible and where it should take place.
2. If the preferred strategic option is *not* considered robust in one or more of the future scenarios, there are two possible routes: [1] you make a so-called contingency plan. In this case, you still adopt and follow the preferred strategic options, even though it is not considered robust. In the plan you specify how to cope with and monitor the factors that were deemed threats, thereby preparing for and mitigating outcomes that may occur and could have major consequences for the company's operations; [2] you reject the initially preferred option and choose to adopt another option that is deemed robust and still in line with the overall vision of the organisation.

Assessing robustness was done for the eight strategic questions and options listed in Table 5. The results of this workshop for drinking water infrastructure in the Netherlands are reported in a Dutch report and are not given here. The following and last sections highlight some major insights and outcomes for Dutch drinking water companies.

5.6 Linking past, present & future: strategic issues for drinking water infrastructure in the Netherlands

Now that we have come full circle, from studying historical events, to exploring the far future and 'back' to actions in the present and foreseeable future, what has the approach contributed in terms of outcomes and insights regarding drinking water infrastructure in the Netherlands? This last section of the chapter provides what the approach generated regarding two water infrastructure themes, namely water treatment of the future and water customer service of the future. Each will be discussed below.

5.6.1 Water treatment of the future: full-scale and fixed or modular and flexible?

One of the strategic questions considered most important by asset managers in Dutch drinking water companies relates to the future treatment of water; will this be done by the use of full-scale, fixed and central treatment systems, by modular, flexible and decentralized units or hybrid systems?

The *historical* analyses showed that full-scale, fixed and central treatment systems have for very long been the standard option, although some space for flexibility or adaptability in options was maintained. Overall though, these systems are characterized by considerable inertia and high levels of path dependency. This means that especially in technological sense, systems require high investments for the long term, and its basic *modus operandi* remains largely the same. Such major systems were initially built following the logic of development and growth in cities or regions: an expanding population and industry, higher levels of welfare and a 'modern' society, which require robust systems capable of treating both increasing quantities and potentially decreasing quality of raw water. This of course also has repercussions for other stages in the water production and distribution process. Preferences of and/or changes in treatment are also very much a matter of what is deemed suitable in a specific context or by management.

Assessing the *future* robustness of the two treatment options (full-scale or flexible) by strategists of the Dutch water companies, indicated that the flexible option is more robust and provides more opportunities under the four future scenarios than the full-scale one, although the latter is still considered a good option. The decentralized option is considered more robust under assumed circumstances of:

- Changing spatial-temporal patterns in water consumption
- Changing demand in types of water services
- Suitability to a self-sufficient lifestyle and society

A transition towards flexible treatment options raises numerous (research) questions, as became evident in a workshop with managers of water companies. Such questions relate to:

- Financial resources: decentralized treatment options require significant financial investments (not only for purchase, but also for operation, for instance regarding energy consumption) and such costs must be legitimized
- Sustainability: what are the environmental impacts of small-scale, flexible treatment units?
- Connectivity with distribution: how to connect smaller units to the distribution network and what are the consequences?
- Protection: how to secure and protect multiple units spread out over the service area?

For these and other issues, a transition to flexible, decentralized treatment units -if desired and in line with one's vision- will likely occur in a stepwise manner, when replacement of an existing system or the building of new systems are due.

5.6.2 Customers satisfaction: water quality, costs or service as main factor?

A second important strategic issue identified for (change in) water infrastructure relate to citizens' or costumers' needs: how will water companies achieve the greatest degree of comfort and the best services for citizens/customers the coming five years?

From a historical point of view, water quality was perceived to be the main driver for attaining customer satisfaction. Later, in the second half of the 20th century, costs became an important driver. Thinking in terms of 'water services' to 'customers' is a relatively recent phenomenon, and is more than the former two a strategic issue that straddles the boundaries between water companies and their customers/citizens. In other words, where water quality and costs are factors that can to a large degree be controlled (internal system), customer services require water companies to think about strategic interaction in the so-called transactional system (see Figure 19).

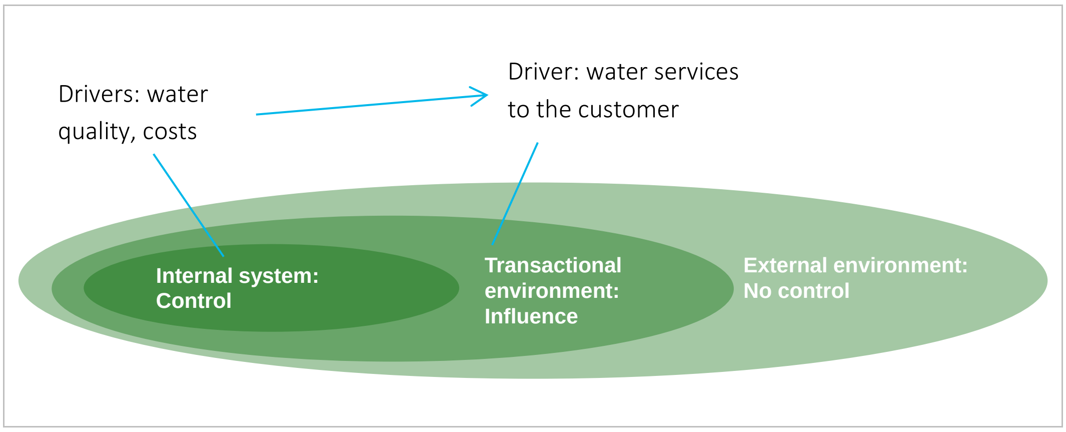


FIGURE 19 WATER QUALITY AND COSTS AS MAIN DRIVERS FOR SATISFYING CUSTOMERS IS COMPLEMENTED WITH ANOTHER DRIVER: THE FOCUS ON CUSTOMER SERVICES

These three factors, water quality, costs and customer service, were also the ones tested on robustness by strategists. Assuming the scenarios of the four cities would indeed unfold in the far future, the most robust strategic option is focusing on the development of water/ customer services. In all scenarios, the importance of customer services is expected to grow only stronger, because of an increased importance attributed to comfort and individuality in most scenarios, but also the tendency to become increasingly self-sufficient requires more attention paid to (tailor-made) services.

Water quality, moreover, will likely remain an important factor irrespective of the type of scenario. Perhaps most striking is the factor of costs; except for in the competitive city, it will lose significance as driver for customer satisfaction. This is rather different from the situation now, whereby costs are one of the main drivers behind the operational strategies of water companies (driven in part also by their shareholders: provinces and/or municipalities). If indeed costs would be attributed less significance and factors such as the quality and type of service more, than this could have major implications for the type of water infrastructure used or the spatial dimensions of water infrastructure (e.g. decentralized units spread out over an area).

If water/ customer services are indeed amongst the main strategic foci of water companies, then there is still the major question how exactly this should take shape. It requires reflection on the type of relation a water company will want to develop with the citizens/customers they serve and their role in the broader environment in which they operate. Is this for instance one of a producer – customer relationship, whereby the water company divides their customer base into segments and develop different types of products for different types of customers? Do citizens perhaps ask for water services to be organized and offered in a 'co-productive' manner, close to one's house and if so, what does this mean for centrally organized water companies and water infrastructure? In any case, multiple issues need to be addressed in this transition, amongst which:

- Demographic/socio-cultural/economic traits of citizen/customer base: What typifies citizens/ the customer base whom are served by water companies?
- Customer/ citizen participation: to what extent, and in what type of (policy/strategy) fields will costumers be asked/ allowed to participate, e.g. in crowdsourcing activities?
- Juridical: how are boundaries shifting in terms of responsibility and accountability?

6 Four future scenarios of the city

The previous chapter already lifted a tip of the veil of the future scenarios created in the project; this chapter will describe the scenarios in full and provides the accompanying illustrations made by a professional artist, Figure 20. The scenarios can be considered concrete “building blocks” or “tools” that strategic planners in water companies can use in their strategic planning processes. The scenarios being ‘ready-made’ is also why a separate chapter is dedicated to them; the strategic planner who intends to use scenario planning, but does not want to build scenarios all from scratch, can readily use the ones here presented. If one is interested in how they came into being and how they can be used in a strategic planning process, then reading the previous chapter is recommended.

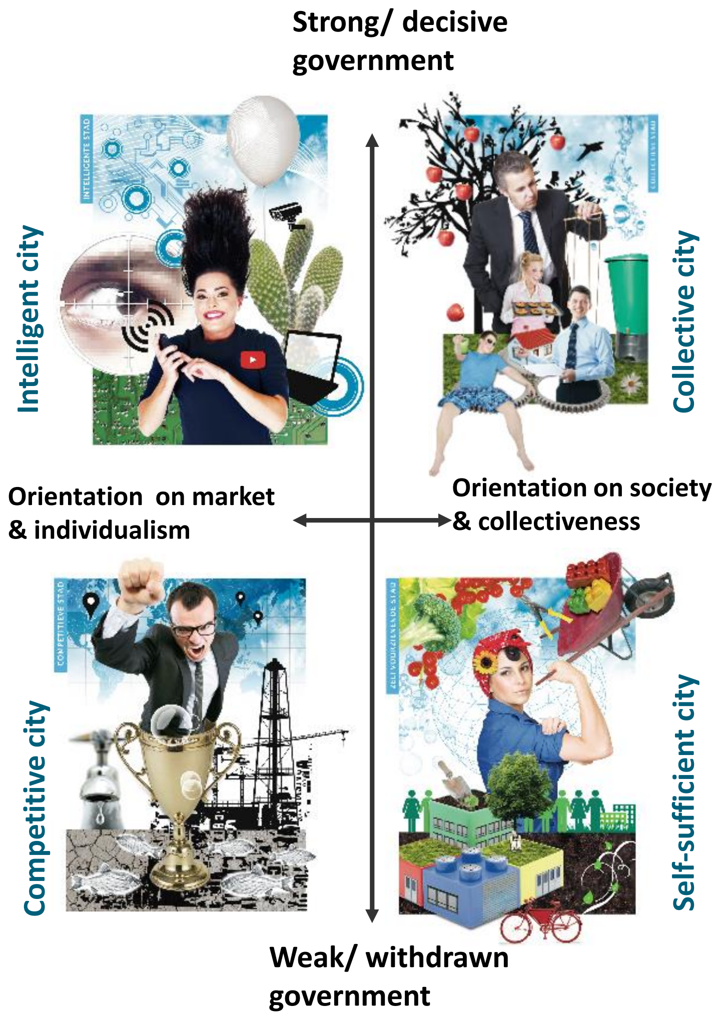


FIGURE 20 THE FOUR CITY SCENARIOS ILLUSTRATED

As the previous chapter showed for the water company Dunea, the scenarios can also be enriched by incorporating specific trends and developments for the city or urban region a planning process is focusing on, thus adapting them to specific contexts.

6.1 The four future, context scenarios of the city

The reader is reminded that the scenarios here presented are all external, context scenarios, as explained in the previous chapter. Each of them provides a unique description and plausible story of how a city might be like in about thirty years from now. The term 'external' or 'context' is used to denote scenario narratives of the intertwined political, economic, social, technological, demographic, juridical and ecological environment in which water companies could be operating in due time. The environments in each scenario know specific enabling and impeding conditions that influence the water sector's operations, whereas vice versa, it is assumed water companies cannot influence such external trends (see paragraph 1.3.2 and Figure 3 for the concept of different spheres of influence). The scenarios thus provide an overview of different urban environments of the future, against which water companies can systematically assess how their strategic intentions and needs work out.

Chapter 5 also already explained in detail how these scenarios originated. To briefly recall; through systematic horizon scanning two key external, uncertain developments were selected which were plotted on two axes, yielding four scenarios. The key uncertain developments that make up these scenarios relate to [A] the size and strength of local authorities and [B] the prevailing societal structure that orients and steers actors and each can be attributed two opposing directions, namely whether [A1] a strong/ decisive local government or [A2] a weak/ withdrawn government is in place and whether [B1] the market and individual serve as the one major structure and orientation in the city vis-à-vis [B2] a dominant orientation on society and collectivism. Together, these axes constitute the fundamentals for the following four future, urban scenarios: the Collective City, the Self-Sufficient City, the Competitive City and the Intelligent City. Figure 20highlights the illustrations of the four scenarios, whereas Figure 21 emphasizes the axes.

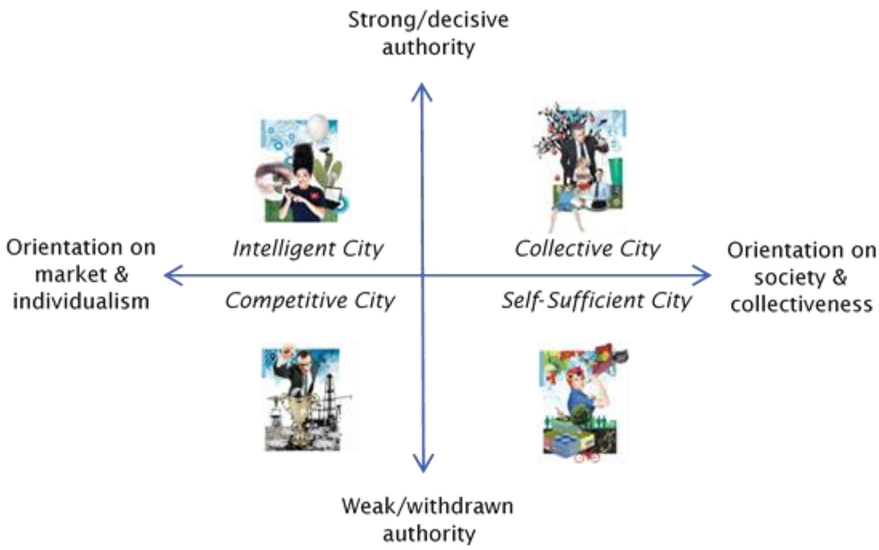


FIGURE 21 TWO AXES, FOUR FUTURE SCENARIOS OF THE CITY

Using scenario's for strategic planning purposes involves a creative process in which participants should be (en)able(d) to rather easily imagine and conceive of the very fabric of a city scenario. The following sections aim to support this by providing the context 'stories' of each city, first in narrative and visual form, followed by the external trends that have been identified as particularly influential on the water sector's operations. These key external trends are summarized in Table 8.

TABLE 8 KEY EXTERNAL TRENDS INFLUENCING WATER SECTOR OPERATIONS

Key external trends	Scale
Trust in drinking water company	High (1) – Low (4)
Importance attributed to sustainability	High (1) – Low (4)
Water demand	High (1) – Low (4)
Regulatory framework	Stringent (1) – Loose (4)
Ownership water entity	Public or private
Political stability	Stable (1) – weak (4)
Availability water	Abundance (1) – Scarcity (4)
Availability resources other than water	Abundance (1) – Scarcity (4)
Pressure on subsoil	High (1) – Low (4)
Climate change	KNMI/WH (1) – KNMI/GH (4)

6.2 The Collective City

FIGURE 22 ILLUSTRATION OF THE COLLECTIVE CITY

The crux of this city is in the name; there is a strong collective sense, which is particularly well reflected in the high levels of trust that citizens place in the local authorities and the city council. The latter is of significant influence when it comes to the number and size of institutions it governs, in terms of legislative powers it can exert and the influence it has on shaping the city in socio-material sense. The city council is highly ambitious. It has a strong normative preference for equality and sustainability in society and it seeks to develop the city and its surroundings such that it can derive essentials like water, energy and food from or in the vicinity of the city as much as possible.

The city is relatively wealthy, which, together with its formative powers, enables it to start up and carry out large-scale projects in line with the aforementioned ambitions.

The city council also assigned specific areas within or just outside the city for functions related to water, food and energy. Large strokes of land, pieces of which were bought one by one by the city in the last decades from private land owners, are for instance. used to growing food. A ditto amount of land is used for generating solar and wind energy. These and other primary services are managed by one centralized utility company. This utility company provides citizens with many of their basic needs. It adopts integrative options in support of sustainable ways of operating and an efficient use and reuse of basic services, thereby limiting the city's dependency on others (e.g. regarding energy or food imports). The central parts of the city are reserved mainly for purposes of living, recreation and professional activities.

Mainly top-down, integrative urban planning means that people are fairly limited in their actions; certain types of recreation, architecture or employment are simply preferred over others and the city actively steers and regulates developments. City entities also try to shape and influence citizen's behaviour and this too sorts effect. People are stimulated to adopt (more) sustainable lifestyles when it comes to for instance (re)use and disposal of food, water, energy and waste, but also as to how communities interact with one another, thereby trying to maintain or enhance social cohesion in the city. Science and technology are considered important in the development of the city and are (therefore) being subsidized. Especially so-called "low risk/ high gain" scientific work is stimulated and subsidized, i.e. tools, methodologies and technologies that are perceived 'robust' and having high potential benefits. An important criterion for subsidy is that scientific outcomes and inventions help develop the city in line with the aforementioned ambitions.

The fairly big, decisive and largely autonomous local government of the Collective City has major steering capabilities, enabling interventions to be effective and objectives to be realized. However, this government can also be characterized as being slightly anonymous, indifferent, authoritarian and 'autistic'; Kafkaesque practices are not unheard of. Sharp criticism from the public on such practices provides for some countervailing power. Ultimately though, as long as a certain level of quality of life is warranted, people take such excesses largely for granted, see Figure 22 and Table 9.

TABLE 9 THE COLLECTIVE CITY IN TERMS OF KEY EXTERNAL TRENDS INFLUENCING WATER SECTOR'S OPERATIONS

Key external trends	Scale	Score Collective City
Trust in drinking water company	High (1) – Low (4)	High (1)
Importance attributed to sustainability	High (1) – Low (4)	Substantial (2)
Water demand	High (1) – Low (4)	Low (4)
Regulatory framework	Stringent (1) – Loose (4)	Extensive (2)
Ownership water entity	Public or private	Public
Political stability	Stable (1) – weak (4)	Stable (1)
Availability water	Abundance (1) – Scarcity (4)	Abundance (1)
Availability resources other than water	Abundance (1) – Scarcity (4)	Abundance (1)
Pressure on subsoil	High (1) – Low (4)	Low (4)
Climate change	KNMI/WH (1) – KNMI/GH (4)	KNMI/G (3)

6.3 The Self-sufficient City

Policies implemented in 2014, aimed at increasing self-reliance and sustainability, have certainly paid off in the decades after. Agenda setters then foresaw –correctly in hindsight– that citizens would increasingly take initiative and responsibility for local, sustainable developments. Such behavior was further stimulated by local politicians promoting the credo of "Big Society". That this occurred against the (political) background of a shrinking and retreating government supposedly committed to doing "more, with less", is often left unmentioned, see Figure 23 and Table 10.

FIGURE 23 ILLUSTRATION OF THE SELF-SUFFICIENT CITY

However this trend may be explained, truth is, the society and citizen of 2040 are markedly different from those in 2014. Citizens are much more critical of the local government than they were then. The 'certainties' that governments held out for citizens weren't nearly as certain as they said they were. Promises of continuous energy supply, climate neutral water management or food security have often not been met the last three decades. But just as critical are citizens of big multinationals, who claimed to be 'green' and sustainable, but were often making vast profits at the expense of people and the environment, here and elsewhere. The consequent void left by the state and the market, has thus largely been filled by citizens themselves. Some have become more conscious about their lifestyle and behaviour and its effects on society and nature. Others simply saw their quality of life slowly but surely deteriorating.

Driven by a vision of society or self-interest; citizens increasingly took matters into their own hands, and public and private organizations followed suit. Their actions are guided by themes such as sustainability, self-sufficiency, locality, craftmanship and simplicity. Imported food from the other side of the world has, where possible, been substituted by food from the private or shared garden. Reusing materials and old stuff for construction, renovation or decoration of houses is now common practice. New homes or neighbourhoods are designed and built in connected ways, commonly equipped with flat, green roofs or even roofs on which park-like environments have been created. So called "low-technologies" that can easily be assembled, maintained and operated by people have taken off and, with the support of high-technologies where needed, serve many puposes, such as refreshing air, treating wastewater or generating electricity. While many of these efforts are aimed at increasing independence from third parties, city entities still play an important, but subordinate role, for example in organizing the circulation of (used) materials. Those small to medium sized companies florish that offer people professional support, materials or courses in such topics as horticulture or the processing of materials.

All this has led to a way of living in the city that has changed quite dramatically over the last decades. The typical hurried, individualistic and materialistic consumer has given way to a large group of socially conscious citizens. Comfort for this group of people is not so much found in materialistic consumer goods. They are more appreciative of and find status in the mastering of (local) knowledge and crafts, although this does not necessarily mean that modern technologies are done away with – items such as 3D-printers can be of great use in their quests for increased self-sufficiency. People work fewer hours per day and fewer days a week than before and spend more time on activities in and around the (largely self-supporting) house. Public spaces (parks, squares, gardens) have increased in number and size and are being used to expose the latest socio-technical features in support of a self-sufficient lifestyle. The city deals with problems relating to climate change by creating or stimulating more green spaces (public and private gardens, roof gardens, etc.) and cars run on hydrogen, which is extracted from water using clean energy sources. Social principles aimed at having a good (but not necessarily perfect) quality of life with relatively few means are embraced by many, while neoclassical economic principles, emphasizing the ‘competitiveness’ or ‘modernity’ of the city, have slowly lost appeal. ‘Less is more’ is the credo of this city.

Although this city and its citizens embrace harmony in society, this is quite often challenged in practice. A sustainable, self-conscious and less individualistic city and the accompanying social initiatives by citizens or city entities, clash regularly with people’s desire for privacy. And while citizen’s dependence on state or market has decreased, they have become more dependent on one another. The functioning of decentralized systems that enable a block of houses to be (partly) self-supporting depends on the joint effort of residents. It makes clear that without a strong social commitment and organization, tensions (a)rise between people, which potentially undermine the foundations on which this society is based.

TABLE 10 THE SELF-SUFFICIENT CITY IN TERMS OF KEY EXTERNAL TRENDS INFLUENCING WATER SECTOR’S OPERATIONS

Key external trends	Scale	Score Self-sufficient City
Trust in drinking water company	High (1) – Low (4)	Modest (3)
Importance attributed to sustainability	High (1) – Low (4)	High (1)
Water demand	High (1) – Low (4)	Modest (3)
Regulatory framework	Stringent (1) – Loose (4)	Mild (3)
Ownership water entity	Public or private	Public
Political stability	Stable (1) – weak (4)	Moderate (3)
Availability water	Abundance (1) – Scarcity (4)	Moderate (3)
Availability resources other than water	Abundance (1) – Scarcity (4)	Moderate (3)
Pressure on subsoil	High (1) – Low (4)	Fairly high (2)
Climate change	KNMI/WH (1) – KNMI/GH (4)	KNMI/GH (3)

6.4 The Competitive City

FIGURE 24 ILLUSTRATION OF THE COMPETITIVE CITY

Remember Detroit; a thriving industrial city in the 1960s with a growing number of inhabitants, of which was little left in 2014. With a flourishing (car) industry, Detroit developed into an economic centre in America and beyond and hosted one of the largest and most profitable companies in the world, General Motors (GM). When GM's focus shifted towards financial services and 'innovation', it began producing financial bubbles rather than cars, which eventually burst in 2005. That had major consequences and these even exacerbated when the mortgage crisis broke out in 2007. GM imploded and massive job cuts were announced and implemented. Many people were forced to leave their homes up to the point that entire districts turned into ghost neighbourhoods. Streets were abandoned and boarded up houses and infrastructure in decay determined its sight. The city even went bankrupt. Crime and poverty peaked. Yet Detroit was able to gradually get back on its feet, flourished once again, but only until the next depression...

Although a one on one comparison is flawed, there are interesting parallels to be drawn between the Competitive City in 2040 and Detroit (and its broader cultural, economic, political context during the first decade of the 2000s). Take for instance the popular credo of the American Dream. The idea behind this –you can achieve whatever you want, as long as you work hard; if you are not successful, blame yourself- is also commonly accepted amongst people in the Competitive City. This idea has a great appeal that provides the majority of people (whether rich, poor, healthy, weak, young or old) with hope and perspective on success. However, from this highly individualistic and 'everyone for himself' mentality gains only a small group, while the majority have a hard time making ends meet. Falling back on public support is hardly possible for the latter group; the local government has been greatly reduced in size and possesses very weak powers. Subsequent welfare state retrenchment have basically eliminated social provisions and these are only discussed during history courses. Goods and resources are (re)distributed mainly through market and money means, two elements that are illustrative for this city. The government's role in this is small and limited to regulatory duties.

In the broader global and regional context economic growth is hard to realize and development and wealth creation is still fundamentally based on the use of fossil fuels. Cities and countries compete for scarce resources like water, space and energy. There is little investment in new technologies, although particular lucrative business opportunities may quite suddenly attract huge investment. This may bring some development and prosperity on the short run, but just as soon as it appears, it disappears. Financial and industry bodies have a great influence on infrastructure development in the city and the country at large. Essential services are hardly cost-effective, unless privatized. All this can be seen as a variant of Schumpeter's concept of "creative destruction" on a city scale. Any concept or development that flourishes is quickly considered a "vivid example" and hence, followed or copied by others. Likewise, what fails is apparently considered unfit by the market and has no further right to exist, or so one believes. People are used to these types of reasoning and act indifferent; there is little you can change by yourself. While for many this is a very stressful existence, there is always that perspective of hope: "tomorrow it could all be different".

Urbanization and concentrated ways of living is positive for most people as that keeps (a minimal amount of) essential services like education and health still accessible. Almost no one owns a car, public transport is expensive and only available on for provider's profitable lines. Hence, people are mostly condemned to easy and cheap ways of moving around, that is, walking or cycling. The city council saves money on public lightning and security, and keeps maintenance of public spaces and services to a minimum. Citizens accept that things break down and remain temporarily or at all unrepaired. They also accept a lower quality of basic goods such as food and drinking water, see Figure 24 and Table 11.

TABLE 11 THE COMPETITIVE CITY IN TERMS OF KEY EXTERNAL TRENDS INFLUENCING WATER SECTOR'S OPERATIONS

Key external trends	Scale	Score Competitive City
Trust in drinking water company	High (1) – Low (4)	Low (4)
Importance attributed to sustainability	High (1) – Low (4)	Low (4)
Water demand	High (1) – Low (4)	Substantial (2)
Regulatory framework	Stringent (1) – Loose (4)	Mild (4)
Ownership water entity	Public or private	Private
Political stability	Stable (1) – capricious (4)	Weak (4)
Availability water	Abundance (1) – Scarcity (4)	Scarcity (4)
Availability resources other than water	Abundance (1) – Scarcity (4)	Scarcity (4)
Pressure on subsoil	High (1) – Low (4)	High (1)
Climate change	KNMI/WH (1) – KNMI/GH (4)	KNMI/WH (3)

6.5 The Intelligent City

FIGURE 25 ILLUSTRATION OF THE INTELLIGENT CITY

In the intelligent city the ideal is (continuous) progress in the modernist sense; all effort is directed towards building a 'modern' city, fully equipped with the newest facilities and latest features. Although the primacy for development lies with the market, it is strongly steered and (re)directed by local authorities. The latter successfully stimulate and subsidize innovation and technology, which enable large, but also small and medium, companies to introduce one after the other (technological) breakthrough. Those are exported to other regions and countries, but are also being used by and implemented in the city itself. That has indeed led to a high-modern city, which –it seems– stands and falls with technology. You can be online anytime of the day, anywhere; public space is full of 'smart' devices designed to make life supposedly more comfortable. Attributes such as telephones and "personality chips" are non-stop connected, so that a range of activities, from shopping to park visits, are continuously being adapted to the (perceived) needs and preferences of the individual. The physical environment and people themselves have become inherently intertwined with the virtual world and only few who can still make a distinction between the two.

This city offers a high degree of comfort and convenience, but it is also the city of great contrasts. A city like this offers citizens many possibilities to participate in a variety of issues, from politics to culture. But a city so dependent on technology also makes for a very fragile society. Technology (e.g. ICT infrastructure) normally runs well, but also fails sometimes, and with the most essential services like water depending on such technical infrastructures, there is more than predicted a break down. And since people's self-reliance has diminished dramatically, such breakdowns often have large effects. All this ironically undermines the concept of 'trust'. One can do without the help of technology no more, but they are also deeply distrustful of it. The increased application of technology and the available data and information may have made the city more 'intelligent', but citizen's dependency on and the automatic processing of information leads to a state of lethargy. One can ask whether this has indeed made citizens wiser.

The intelligent city will be most useful to those who fully expose themselves and their characteristics, experiences and preferences. Availability of data and information, and increased transparency better enables various actors (citizens, companies, authorities) to inform themselves, but this has come with reduced privacy. This may lead to information being used for other than intended purposes. Whether or not this is indeed the case; the fear for the latter is constantly present. That fear penetrates deeply and divides citizens, and their relation with official authorities. Finally, psychosocial symptoms are widespread. This however, is not necessarily seen as a social problem, as it perceived as a new ‘market’ that can be ‘conquered’ with the newest innovations, see Figure 25 and Table 12.

TABLE 12 THE INTELLIGENT CITY IN TERMS OF KEY EXTERNAL TRENDS INFLUENCING WATER SECTOR’S OPERATIONS

Key external trends	Scale	Score Competitive City
Trust in drinking water company	High (1) – Low (4)	Substantial (2)
Importance attributed to sustainability	High (1) – Low (4)	Modest (3)
Water demand	High (1) – Low (4)	High (1)
Regulatory framework	Stringent (1) – Loose (4)	Stringent (1)
Ownership water entity	Public or private	Private
Political stability	Stable (1) – weak (4)	Substantial (2)
Availability water	Abundance (1) – Scarcity (4)	Critical (3)
Availability resources other than water	Abundance (1) – Scarcity (4)	Critical (3)
Pressure on subsoil	High (1) – Low (4)	Modest (3)
Climate change	KNMI/WH (1) – KNMI/GH (4)	KNMI/W (2)

Part III

Conclusions and Recommendations

(based on part I and II)

7 Conclusions & recommendations

In this book we describe how water companies can take an uncertain future into account in strategic planning for their drinking water infrastructure. Because investments in drinking water infrastructure are usually for the long term it is important to consider the future context in which the infrastructure has to operate. The future is in itself uncertain; various important factors may change, such as the source water quality (nitrate, emerging substances, etc.), legislation (e.g. tax on ground water extraction), stakeholders' expectations (e.g. as other stakeholders appear, or their role changes) and the infrastructures' condition and function. Furthermore, social, economic, technical en societal trends may impact the (future) infrastructure. This research treats drinking water infrastructure (extraction, treatment and distribution) as a socio-technical system, meaning that not only the technical aspects are considered but also the social context in which the infrastructure functions.

We have noted that for many decisions on infrastructure investments the future is only considered in a limited way. For instance, operational investments only consider a limited time horizon when a specific pipe is replaced with the same pipe diameter, or strategic investments only consider one (most likely) future when a replacement transport network is designed with smaller diameters to cater for expected decrease in demand. Often a safety margin is added for potential growth. In the past, the drinking water companies took an expected increase in demand into account; the large demand predictions of the 1970s, however, were not fulfilled. Strategic decisions often are the result of a one-sided approach towards the future, when only current criteria for investments are considered, a mono- disciplinary attitude is taken, or only one future scenario is studied. It is assumed that one future is usually most likely or an anticipated worst case scenario, where in reality the future in itself is uncertain. In this study a scenario planning approach using explorative external scenarios is adopted to overcome this issue.

We distinguish three stages in deciding on long term investments for drinking water infrastructure (Figure 26):

1. Determining the starting point and preconditions by looking at past and present.
2. Determining the investment options following from the water companies long term vision; alternative options are widely considered.
3. Deciding on the investment and plan for the implementation. All options are tested on their robustness in several distinct future scenarios where important trends that need to be monitored and which partners are required to reach the goals with are reflected on.

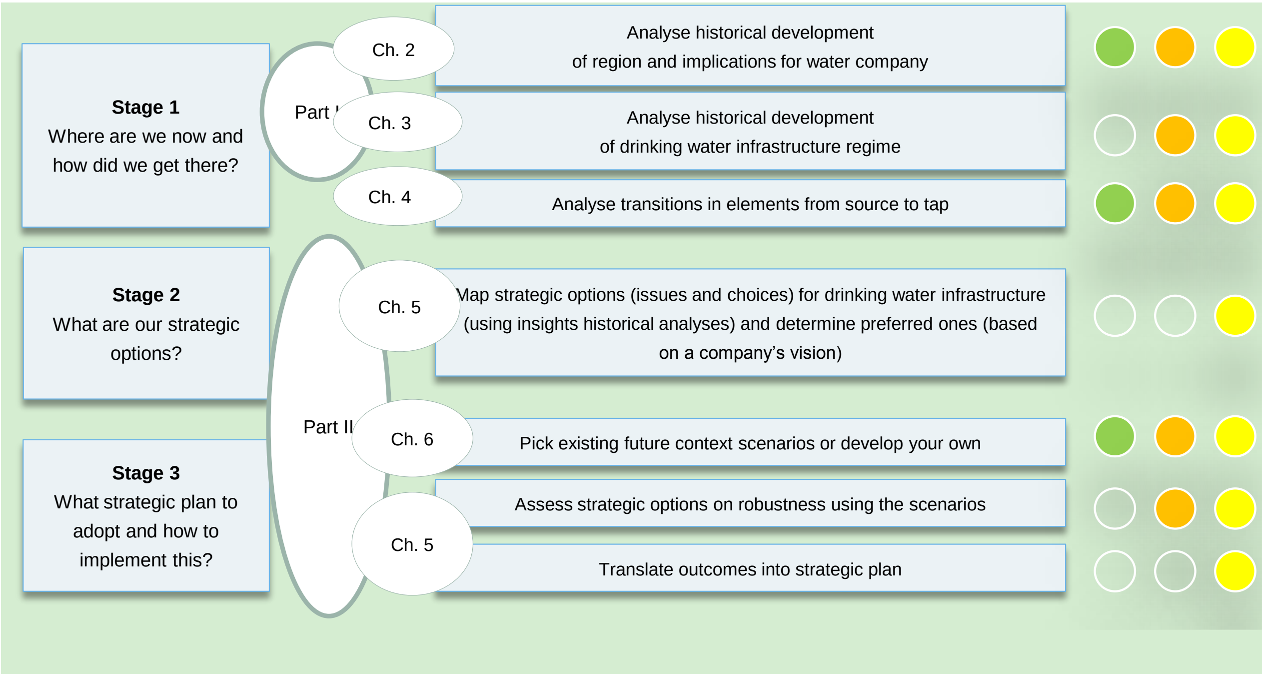


FIGURE 26. STAGES TOWARDS A STRATEGY ON DRINKING WATER INFRASTRUCTURE, WHILE TAKING INTO ACCOUNT AN UNCERTAIN FUTURE. THIS BOOK IS A GUIDANCE FOR WATER COMPANIES TO CONSTRUCT THEIR VISION AND SECTIONS CAN BE USED AS EITHER A FOUNDATION (GREEN DOTS), AS A STARTING POINT (ORANGE DOTS), OR AS AN INSPIRATION (YELLOW DOTS).

This book provides a guide and building blocks and inspirations on each of the three stages that can be used by water companies to construct and implement their own strategic planning process regarding their future drinking water infrastructure. They can be used as a foundation (use as is), as a starting point (i.e. expand on this with extra studies along the lines described here, or made more specific for own use), or as an inspiration (but own studies will be used instead). We do not offer foundations in every step, as some of the steps are very company specific or specific for the Dutch situation, but we do offer inspiration, drawing on workshops held with a delegation of the ten Dutch water companies and a specific implementation of drinking water company Dunea.

For stage 1 we have described the historic development in the Netherlands (in some respects exemplary for Western Europe more generally) and the impact on infrastructure on the scale of a country or water company. This provides insight into drivers for investments over the past 100 to 150 years. We also looked in more detail into water companies' investments in infrastructure since their establishment. This showed how early choices for water sources and locations of treatment works have significant influence on future planning; we found evolution rather than revolution in infrastructures. Drivers for investment are largely determined by the societal context: in the past water quantity (supplying all) and then water quality were main drivers; currently cost, sustainability and customer satisfaction compete alongside water quality. There is flexibility in infrastructure, but changes take a long time. A water company may review past decisions on infrastructure and see if they still hold, or that a transition to a better solution may be beneficial. We looked at transitions in the choice of source water, treatment schemes, networks design and drinking water demand and found that these typically take 20 to 30 years and may either lead to full transitions, limited transitions or back lashes. We advise the water companies to monitor key uncertainties, but also to try to influence them with suitable partners.

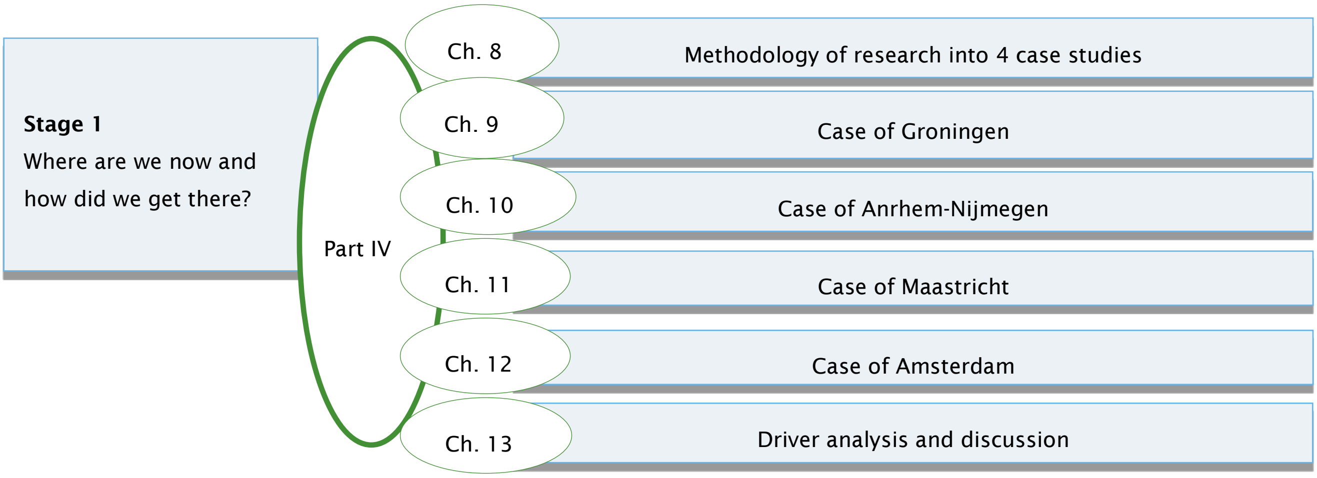
Stage 2 is very company specific, but we have included some examples on investment dilemmas: 1) to continue with centralized treatment facilities (with the economy of scale) or move towards more decentralized facilities or centralized with a more modular approach, 2) to prevent any possible inconvenience for customers or to manage customers' expectations with respect to an aging infrastructure and the cost to maintain it, 3) Dunea's process towards a new five-year strategic plan for the period 2015 – 2020.

For stage 3 we have developed context scenarios for future cities along the axes of A) the size and strength of local authorities and B) the prevailing societal structure that orients and steers actors. This culminated into four views for the extremes of the axes that are called 1) the collective city, 2) the self-sufficient city, 3) the competitive city and 4) the intelligent (or smart) city. The descriptions of these cities and the accompanying illustrations support in contemplating and discussing the investment consequences in the various possible futures. The options defined in stage 2 were discussed for the four context scenarios in a workshop with the ten Dutch water companies and also specifically within water company Dunea. The outcome of the discussions could be an input for an investment plan that is considered robust under all possible futures. The future scenarios can easily be enriched, made more specific for a region or be used for discussions with not just water company decision makers but also with other stakeholders. We advise water companies to apply the method to current investment dilemma's.

Part IV

Historical development of four Dutch urban drinking water infrastructures

The following part of the research, and the accompanying chapters, will be described in Part IV:



8 Introduction to case studies

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.

9 Groningen

9.1 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 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.

9.2 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 27). 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.

9.3 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)[7] 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 27).

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.

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

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

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.

9.5 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.

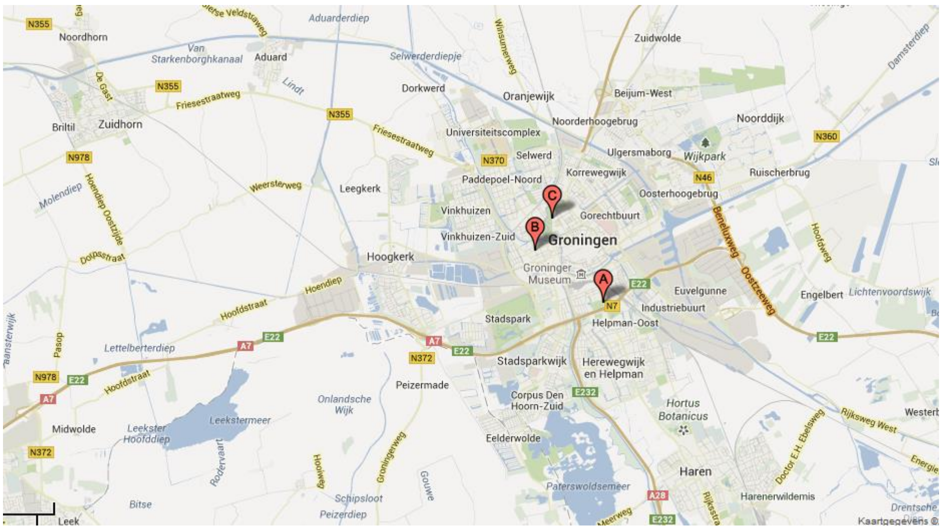


Figure 27; Water towers in the city of Groningen (A = South tower; B = West tower; C = North tower). Source google maps.

9.6 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 28.

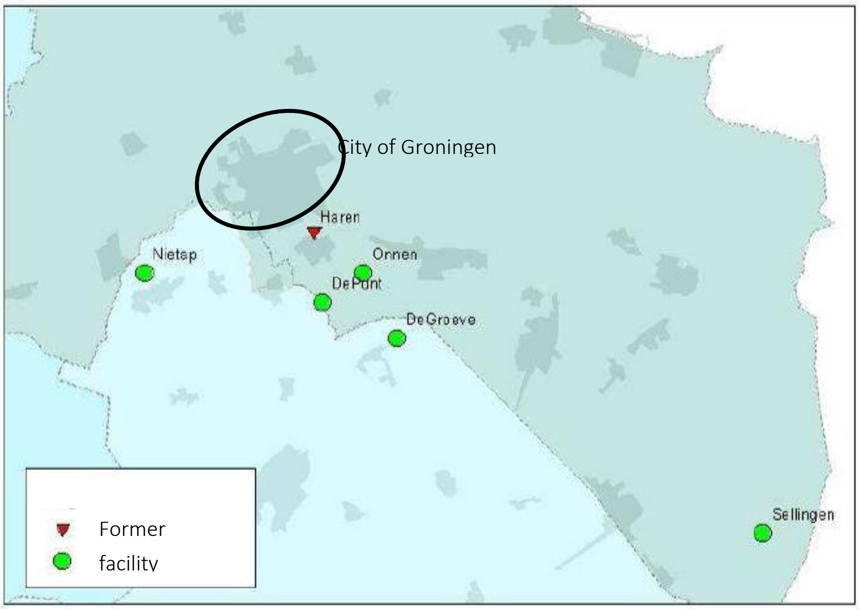


FIGURE 28; OVERVIEW OF THE FACILITIES OF GRONINGEN IN 2014 (LEUNK, 2012)

9.7 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.

9.8 1980 – 2000: Service area isolation and demand stagnation of municipality, and merger to Waterbedrijf Groningen

In the 20th 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'.

9.9 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.

9.10 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.

9.11 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 rationale 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.

9.12 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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C. Melessen-Moerman, Waterbedrijf Groningen, October 2013

10 Arnhem – Nijmegen

10.1 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 29.

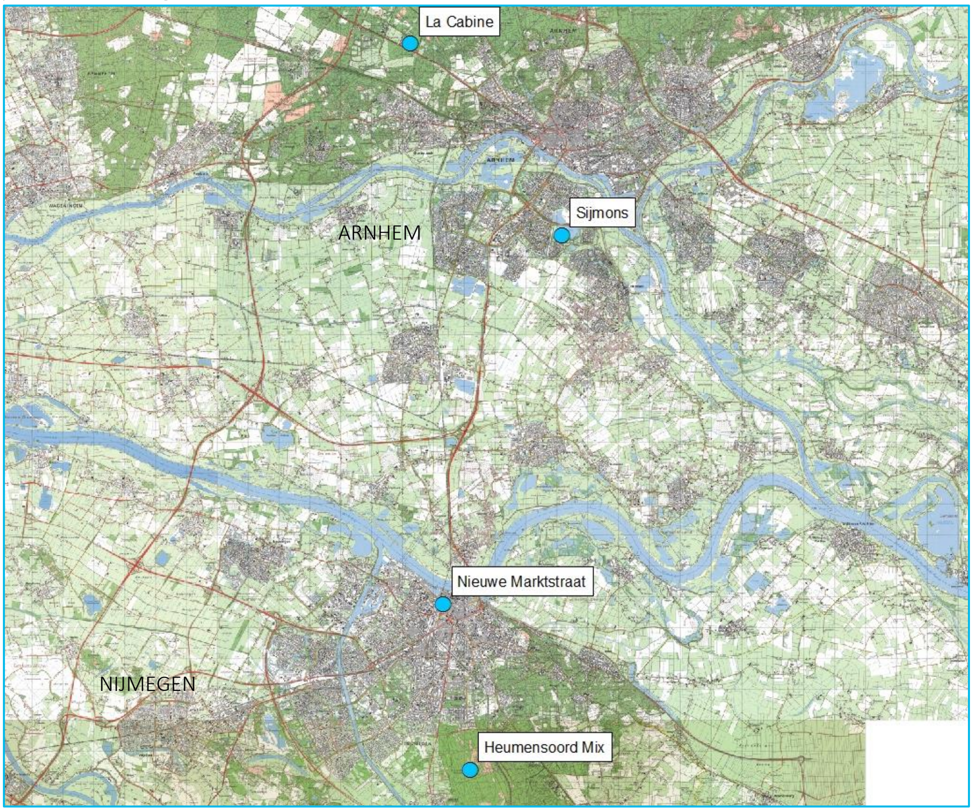

FIGURE 29; OVERVIEW OF URBAN AREA AND PRODUCTION FACILITIES OF ARNHEM AND NIJMEGEN IN 2014.

10.2 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.

10.2.1 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.

10.2.2 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.

10.2.3 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 21st 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.

10.2.4 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.

10.2.5 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.

10.2.6 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).

10.2.7 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.

10.2.8 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.

10.3 Nijmegen

10.3.1 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.

10.3.2 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.

10.3.3 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.

10.3.4 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.

10.3.5 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.

10.3.6 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.

10.3.7 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.

10.3.8 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.

10.4 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.

10.4.1 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.

10.4.2 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.

10.4.3 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.

10.4.4 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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10.6 Interviews

November 2013 – January 2014

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

11 Maastricht

11.1 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 30, according to the situation in 2014 (except Borgharen and Caberg which have been shut down).

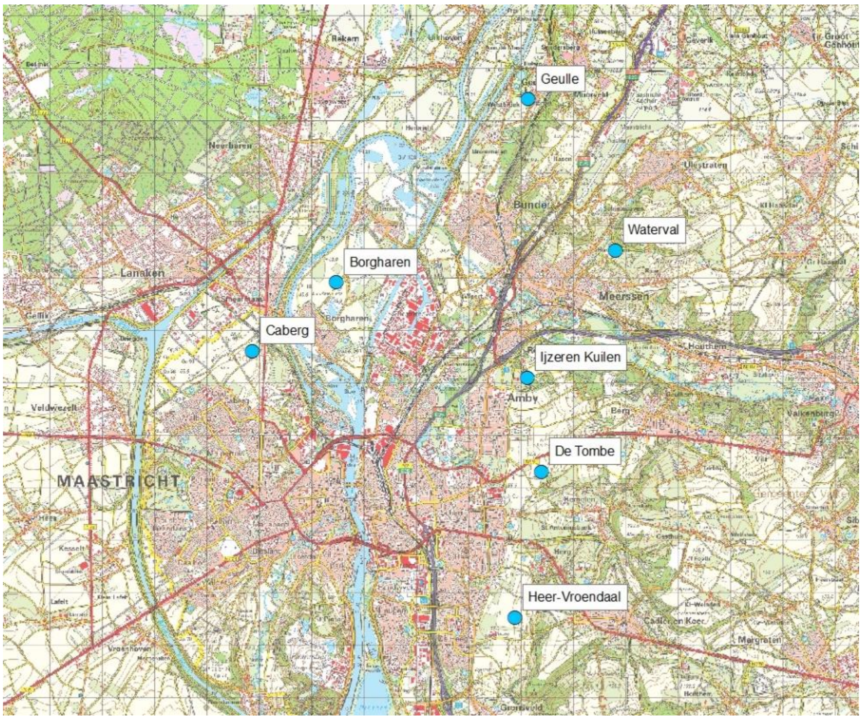

FIGURE 30; OVERVIEW OF URBAN AREA AND PRODUCTION FACILITIES OF MAASTRICHT IN 2014 (BORGHAREN AND CABERG ARE CLOSED).

11.2 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.

11.3 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.

11.4 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.

11.5 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.

11.6 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.

11.7 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.

11.8 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.

11.9 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).

11.10 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.

11.11 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.

11.12 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 21st 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.

11.13 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.

11.14 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 21st 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.

11.15 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.

11.16 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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11.18 Interviews

October – December 2013:

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

12 Amsterdam

12.1 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-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.

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

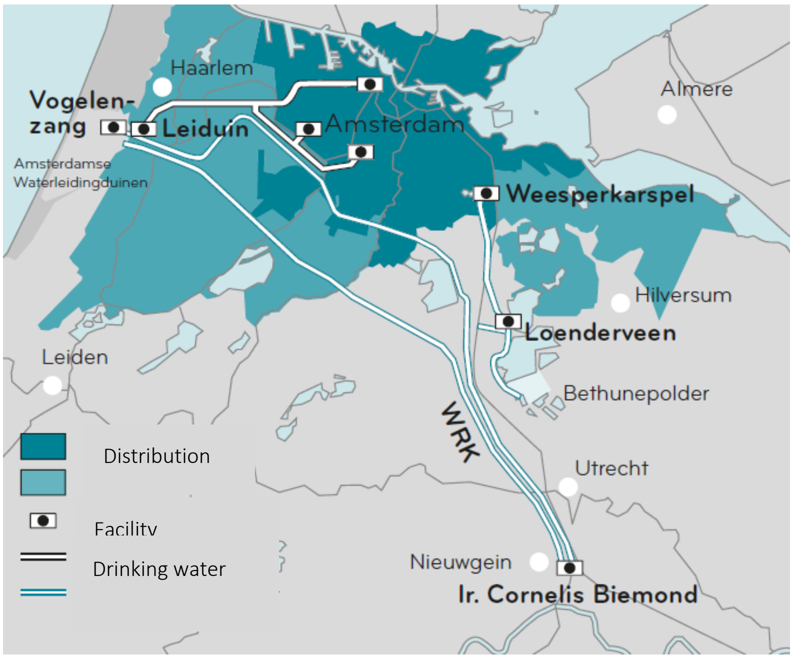

FIGURE 31; OVERVIEW MAIN INFRASTRUCTURE WATERNET (STATUS 2014).

12.2 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.

12.2.1 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.

12.2.2 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.

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.

12.2.3 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).

12.2.4 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.

12.2.5 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.

12.2.6 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.

12.2.7 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.

12.2.8 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.

12.2.9 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.

12.3 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.

12.3.1 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.

12.3.2 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.

12.3.3 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.

12.3.4 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.

12.3.5 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.

12.3.6 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.

12.3.7 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.

12.3.8 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.

12.3.9 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.

12.3.10 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.

12.3.11 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.

12.3.12 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.

12.4 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 20th century, in 2014 the investing in such a capacity increase is no longer expected to be necessary for the urban area of Amsterdam.

12.5 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.

12.6 References

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12.7 Interviews

Period: October – December 2013.

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

13 Driver analysis and discussion

13.1 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 13.

TABLE 13; DRIVER CLASSIFICATION (DRIVER CODES ARE REFERRED TO IN TABLE 14 - TABLE 17)

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)[8]
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

[8] 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.

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 14 - Table 17 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 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.

13.2 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 14; DRIVERS HISTORICAL DEVELOPMENT DRINKING WATER INFRASTRUCTURE GRONINGEN (DRIVER CLASSIFICATION CODES REFER TO TABLE 13).

Year	Investments or occurrence	Driver	Classification driver	Internal/ Trans/ External
1880 1923 ± 1930	▪ Determining type and location of drinking water source. ▪ Investments in drinking water treatment (adaptation, expansion, optimization), in order to remove different kinds of substances (e.g. macro-ions, particles, esthetic parameters, microbiological). For instance: ▪ Rapid sand filtration ▪ ozonation	Water quality demands	WQ	EX IN
1880 - 1940	▪ Several expansions of different facilities: Extraction, treatment, storage capacity, and transport pipeline capacity. ▪ 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 CUST	TR
1911 - 1918	Establishment of a new water company	▪ Disagreements on	ORG	TR

	Including its required facilities such as catchment, treatment, transport and distribution. Leading to double distribution systems in some parts	water service concessions ▪ Relationship between two water companies		
1947	Reconstruction	Damage during war	RNV	EX
± 1930	▪ Groundwater wells ▪ Additional filtration ▪ Mixed treatment	Discovery of groundwater (abundant and good quality)	WQ AVB	IN EX
± 1935	Covering of facilities	▪ Prevent growth of algae ▪ Increase time between cleaning	WQ OP	EX
± 1965	Shut-down of ozonation Investment in chlorination?	Control microbiological drinking water quality in alternative manner	TECH 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: ▪ Construction of new facilities ▪ 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 WQ POL	EX
Entire period	Several projects	Reliable water supply	SEC	TR
± 1975 - 2005	Investment in deep infiltration of drinking water	▪ Secure water supply ▪ Stimulation by policy makers ▪ Prevent upcoming of brackish water ▪ Water quality	WD/SEC POL WQ	TR EX

		improvements		
± 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 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 ▪ Agreements on reduced groundwater usage Leading to improved source water quality ▪ Reduce outdoor influences on water quality	POL WQ GEO	IN, TR, EX
± 1960 - 1970	Separation of surface water and groundwater treatment	Progressive insight and increase of groundwater usage	AVB WQ	IN
± 1995	Construction of mixing reservoir leads to smoothing of quality	▪ Large quality variations of source water ▪ 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	€ TECH	IN
± 1980	Occurrence rather than investment Confirmation that groundwater is needed ad source (justification of investments)	Large variations in flow of surface water, little storage capacity of raw water	WQ AVB	EX
1988	Shut-down of post-chlorination	Discovery of harmful disinfection byproducts	WQ	TR
1998	(occurrence rather than investment): Merger of municipality and provincial water company	▪ Stagnation of growth of service areas and water demand, leading to expected increase of water price ▪ Legal statement regarding the minimum size of drinking water company	ORG	TR
± 1999	Shut-down of membrane filtration research	▪ Costs ▪ Different perspectives regarding membrane filtration and preference for groundwater treatment	€	IN
± 2000	Reinvesting in surface water treatment	▪ Agreement on	POL	IN

		reduction of groundwater extraction ▪ Efforts on surface water quality improvements have turned out successful ▪ Reliable water supply	WQ SEC	
± 2005	Shut-down of deep infiltration	▪ Costs (small capacity and need for renovation) ▪ Capacity ▪ Security of supply	€ SEC	IN
± 2011 Future	▪ Shut-down of one smaller ground water facility ▪ Considering to shut down a second facility	▪ Preference for surface water ▪ Possibility for purchase of drinking water	WD €	IN
2005	Installation of UV disinfection and temporary chlorination	Campylobacter contamination	WQ TECH	IN
2012	Revamp of UV installation	Biologically unstable drinking water	WQ	IN
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 €	IN
Future	Possible large adaptation of transport pipeline system	▪ Risk for damage to third party property ▪ Plans of third parties to broaden the highway	IMG €	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 Construction of storage reservoirs	▪ Limited storage capacity of water towers ▪ Progressive insight regarding storage and distribution	TECH WD	IN
1998 - present	Construction of connections between municipal and provincial distribution network	Integral consideration of reliability of water supply after merger	P SEC 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 HIST	IN

± 1970	▪ Construction of transport pipeline ▪ Purchase of land (for facility development purposes)	Rapid expected increase of water demand of new port	WD	IN EX

13.3 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 15; DRIVERS HISTORICAL DEVELOPMENT DRINKING WATER INFRASTRUCTURE ARNHEM-NIJMEGEN (DRIVER CLASSIFICATION CODES REFER TO TABLE 13).

Year	Investments or occurrence	Driver	Classification driver	Internal/ Trans/ External
ARNHEM				
1885	Construction of high reservoir rather than water tower	▪ Costs ▪ Geographical situation	€ GEO	IN EX
± 1909	▪ Construction of reservoir ▪ Construction of pumping facility ▪ Construction of water tower	Keep water pressurized during increasing water demand	WD 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 ▪ Construction of temporary facility ▪ 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 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 ▪ 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, water quality	TECH? WD? WQ?	EX IN
1953 - 1958	Renovation of existing treatment facility	Condition	RNV	IN
1968	Construction of additional wells	▪ Increasing water demand ▪ Obtained extraction permit	WD POL	EX TR
1978	Construction of new booster	Improve water supply	SUP	IN

			P	
1980	Construction of new facility (Location moved from north to south)	Current facility cannot meet required water demand (spare groundwater at natural reserve area)	WD (POL)	EX (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	€ WQ	IN
1930 – 1960	▪ Growth of number of shallow wells ▪ Graduate switching from shallow to deeper extraction ▪ Graduate decrease of number of wells	▪ Increasing water demand ▪ Technological possibilities ▪ Water quantity and quality	WD TECH AVB WQ	EX 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 ▪ Shortage of groundwater during low river levels	POL GEO	TR
± 1950	Construct additional reservoir	Growth of city and growth of water demand	WD	EX
± 1990	Expand filtration capacity to reduce filtration velocity	Customer complaints on brown water	WQ CUST	TR
± 2000	Repeatedly decided not to invest in softening	▪ Costs and priority ▪ Customer satisfaction	€ CUST	IN
Entire period	Divide distribution system into pressure zones	▪ Meet pressure standards ▪ Limit energy usage ▪ Prevent failure distribution system	P E €	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 E €	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 ▪ Geographical situation	SEC GEO	EX IN
1909, 1920	▪ Repeated expansion of facility capacity ▪ Construction of second facility	Growing water demand	WD	EX

1940				
± 1995	Install marble filtration for condition of water	Prevent damaging of cement distribution pipelines	€ WQ	IN
1985	Expand facility with water treatment	▪ Shut-down of two large groundwater extracting parties (paper industry), leading to raw water quality changes ▪ Drinking water quality not compliant with future drinking water standards	3rd WQ POL	EX
± 1980	Testing and installation of air stripping	Groundwater pollution	3rd 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 ▪ Restore capacity of polluted site ▪ 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 ▪ Limit permitted groundwater extraction ▪ Redundancy ▪ Costs (scale-up?)	3rd WQ POL SEC €	EX TR IN
1990s	Renovation and install automation	• Operational for long period, poorer condition. • Manual operation leading to higher energy and water usage.	RNV €	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 instead.	3rd POL WD	EX
ARNHEM-NIJMEGEN AREA				
± 2002	Occurrence rather than investment, but leading to a change of planned investments: 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 SUP/SEC €	IN
± 2002	Occurrence rather than investment, but leading to a change of planned investments: The larger, or stronger, or more influential company may change the existing investment plans of the other company. Or investment plans of both	Merger of companies	ORG SUP/SEC €	IN

	companies are changed because of renewed integral considerations. Changed investment plans comprise: ▪ Expand treatment facility and transport additional groundwater from other sites ▪ Cancel the planned investment in a new facility at the latter sites ▪ Serving of Achterhoek region ▪ Serving of Nijmegen and Arnhem, leading to adapted pressures in certain districts	In this specific case: ▪ Different insights ▪ New, larger scale of operation ▪ Desire for scale-up		
± 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 ▪ Compensation by transport of drinking water via newly constructed pipeline works ▪ Construction of softening plants, clustered treatment ▪ Decided not to invest in the purchase of drinking water	▪ Serve softer water ▪ Scale-up by clustering and shutting-down smaller facilities ▪ Reduce dry-out of soil ▪ Self-sufficiency	CUST SUP/SEC ORG € DEP	IN
± 2005	Transport pipeline construction for drinking water transport	Sparing of natural reserve, leading to reduction of groundwater extraction permit	POL	TR
± 2000	▪ Infiltration facilities ▪ Change to deeper aquifers	Sparing of natural reserve, reduce dry-out of soil	POL	TR
2002 - Future	▪ Reduction of permitted extracted groundwater ▪ Shut-down of facilities and optimization of other facilities	▪ Inhibit development of third parties ▪ Overcapacity (number of extractions and annual permitted capacity)	3rd POL SUP/SEC €	TR IN

13.4 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 16; DRIVERS HISTORICAL DEVELOPMENT DRINKING WATER INFRASTRUCTURE MAASTRICHT (DRIVER CLASSIFICATION CODES REFER TO TABLE 13).

Year	Investments or occurrence	Driver	Classification driver	Internal/ Trans/ External
1880	Extraction, pumping and distribution facilities	▪ Establishment ▪ Water demand	WD	EX
1886	Under water pipe	Connect both sides of river	GEO SEC AVB	EX
± 1916	Search and test new extraction facility	Development of other towns	3rd WQ	EX

			WD	
1918	Acquire extraction site	Future development plans	WD SEC	IN
1921	New production facility on other side of the river	▪ Water demand ▪ Water pressure ▪ Desire for facility on west side	WD P GEO	EX IN
1926	Chlorination	Public health	WQ	IN
1920	Damage and repair of production facility	▪ River flooding ▪ Security of supply	GEO SEC	EX
1925	Construction of new production facility	Customer complaints about water quality and continuity	SEC WQ CUST	EX
1925	Sell production facility to industry	New facility available	AVB	IN
1886	High reservoir constructed at hill	Water demand and continuity	GEO SEC	EX
1932	New reservoir	▪ Security of supply ▪ Energy cost reduction	SEC € / E	EX IN
1927	Construction of new wells	Research availability of deeper groundwater on the west side of the river	WQ AVB	IN
± 1930	▪ Sell mineral source well to private enterprise ▪ Renovation of existing facility	Deeper groundwater was of no use for drinking water purpose	WQ WD	EX
1945 - 1960	Fix bore well of private party	Contamination groundwater with brackish mineral water	3rd WQ SEC	EX
1960	Shut-down of production facility	▪ Water quality, situated in city center ▪ Availability of alternative production site	AVB WQ	IN
1930 1950	▪ Purchase of site for extraction tests ▪ More extraction tests	Search and test alternative sources, on the west side of river	WD SEC AVB	IN
Entire period	Extraction of groundwater	Avoid high groundwater levels and nuisance	GEO CUST	IN → TR?
± 1945 – 1950 1945	Occurrences/actions ▪ Water supply planning ▪ Limit waste of drinking water ▪ Agreement with private parties on supporting water supply Additional well	▪ Water demand increases ▪ Existing facilities reach limits	WD SEC	EX
± 1950	Adapt transport pipeline	▪ Security of supply ▪ Outside	GEO SEC	EX

		temperature conditions		
1950 and further	Construction of deeper wells	▪ Technological development new pumps ▪ Higher costs of former extraction ▪ Extraction by different water company	TECH € 3rd	EX
1949	New transport pipeline	Security of supply	SEC	IN
1953	▪ Construction of new facility ▪ Raw water treatment	▪ Water demand ▪ Raw water quality	WD WQ	EX
1952	Construction of new reservoir	Remain sufficient pressure, despite growing demand	P	EX
1976	Shut down of production facility	▪ Water quality issues ▪ Expanding of the city	WQ 3rd	EX
1975	Start-up of new facility	Replacing shut down facility (Water demand)	WQ 3rd WD	EX
± 1988 ± 2010	▪ Expand treatment with UV-disinfection ▪ Removal of UV installation	▪ Public health ▪ Groundwater pollution ▪ Improvement groundwater quality	3rd WQ	EX
1940 – 1965	▪ Research extraction alternatives ▪ These alternatives showed insufficient capacity and quality	Desire to stay independent of provincial water company and to stay self-sufficient?	DEP ORG GEO	IN EX
1930 - 2000	▪ Research extraction alternatives	▪ Extraction by other parties (water company, cement industry) ▪ Poor availability water on west side	3rd GEO	EX
1978	Construction of new facility	Capacity problems at other production site because of extraction by other water company	3rd WD	EX
1999 - 2008	Construction of softening plant and transport pipelines	Customer satisfaction	CUST	IN
± 2000	Lay-out of the centralized softening ▪ Connect De Tombe (municipality) ▪ Shut-down Dommel (WML) ▪ Shut-down Borgharen and Caberg (municipality)	▪ Cooperation and merger ▪ Water supply plan	€ ORG SUP GEO	TR

		▪ Costs (clustering)		
2000	Shut-down The Dommel	▪ Costs ▪ Water quality ▪ Alternatives available	€ WQ SUP	IN
2008	Shut-down Borgharen and Caberg (municipality)	▪ Availability from other production facilities ▪ Water quality: hardness, risk of flooding, third party activities)	SUP € WQ GEO 3rd	EX IN
1998 - present	Investing in cooperative program with farmers	▪ Water quality ▪ Nitrate standard ▪ Agricultural activities	3rd POL GEO WQ	TR
1999 – 2008	Occurrence rather than investment, but leading to a change of planned investments: 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 SUP/SEC €	IN
> 1960	Break-down of reservoir	Activities of cement industry	3rd	EX
± 2010	▪ Expanding reservoir capacity ▪ Renovation of reservoirs and boosters	Security of supply and asset condition	SEC RNV	IN
Entire period	Several different kinds of river crossing transport pipelines	▪ Security of supply ▪ Major production on east side	SEC GEO AVB	EX

13.5 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 17; DRIVERS HISTORICAL DEVELOPMENT DRINKING WATER INFRASTRUCTURE AMSTERDAM (DRIVER CODES REFER TO TABLE 13).

Year	Investments or occurrence	Driver	Classification driver	Internal/ Trans/ External
Mostly LEIDUIN				
1853	Start-up Leiduin site Transport pipeline (23 km)	Transport water from production site to the city	SUP	IN
1888	Construction of the second treatment facility (WPK)	▪ Water demand ▪ Water pressure ▪ Availability dune water	WD P AVB	EX
1900	Renewing and expanding facilities	▪ Growth of city	WD	EX

		▪ Water quality	WQ	
Entire period	Many transport pipeline works. Also river, canal and lake crossings.	▪ Water supply plan ▪ Security of supply	SEC WD SUP	EX
1920	▪ Deeper extraction ▪ Construction of pre-filtration	▪ Availability of shallow water ▪ Changed raw water quality	AVB WQ	EX
1920s-1930s	▪ Expanding pre-filtration and slow sand filtration ▪ 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 WQ	IN
1920s	▪ Additional transport pipelines ▪ Additional booster station	▪ City growth by annexation ▪ Low water pressure	WD P	EX
1929 – 1934	▪ Occurrence: Decision to adapt Weesperkarspel plant for drinking water purpose ▪ Research possibilities of alternative sources for Weesperkarspel ▪ Research possibility of dune infiltration ▪ Plan: artificial infiltration in dunes + expanding and improving Weesperkarspel	Growing water demand cannot be met with one production facility	WD WQ AVB	EX
1948	▪ Fourth transport pipeline between dunes and city. ▪ With several cross connections ▪ Material choice: concrete instead iron	▪ Water demand ▪ Continuous water supply ▪ Scarcity of iron	WD SEC SCAR	EX EX
1953	Expand storage capacity	▪ Water demand ▪ Continuous water supply	WD SEC	EX
1950s	Covering of slow sand filters	▪ Prevent freezing ▪ Prevent algae growth	WQ GEO	EX
1952 1954-1957	Establishment of WRK (transport of river water to dunes) Construction of WRK-I comprises: ▪ Pre-treatment facility ▪ Transport pipeline\ works	▪ Growing water demand (household and industry) ▪ Limited amount of dune water ▪ Ability to rely on existing dune facilities / dependent on historical infrastructure	WD AVB € HIST	TR 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	WQ	IN

		quality	(OP/€)	
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 ▪ Renewal	▪ Growing water demand ▪ Security of supply ▪ Condition of assets	WD RNV	EX IN
1960s	▪ Powder carbon dosage installation ▪ Chlorine dosage installation	Source water quality Meeting standards	WQ POL	EX IN
± 1965	Construction of WRK-II comprising: ▪ New transport pipelines ▪ Expanding of pre-treatment facilities	Growing water demand	WD	EX
Future	Occurrence: New contract negotiations might have impact on exploitation of WRK	Contract expiration	CONTR 3rd	TR
1960s	▪ New transport pipeline ▪ Construction booster station ▪ Expanding storage capacity ▪ Construction of additional storage facility	▪ Improving transport capacity ▪ Water demand, limited capacity of existing works ▪ Balance pressure variations	SEC WD P	IN EX
1960s	Installing of 100.000 non-return valves	Prevent contamination of drinking water	WQ 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 ▪ Continuous water supply	WD 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: ▪ Public health (water quality), energy, environment	CUST WQ E ENV	IN
1995	▪ Construction of ozonation ▪ Construction of activated carbon ▪ Weesperkarspel was adapted prior to Leiduin	▪ Raw water quality changes (pollution) ▪ Improve treatment to newest technical standards ▪ Meet Decree and company-specific quality standards	WQ TECH POL € PLAN	IN EX
± 2012	▪ Renovation of ozonation, however:	▪ Asset condition	WD	EX

	▪ 4 of the 5 chambers are renovated, one is taken out of operation	▪ Stabilization of water demand		
> 1960	Repeated consideration for covering of raw water collection. No investment yet	▪ Protection of reclaimed raw water quality ▪ Costs ▪ Historical development of infrastructure	WQ € HIST	
Mostly WEESPERKARSPEL				
1888 – 1930s	Occurrence: Weesperkarspel water did not qualify for drinking water purpose. Existence of two different water qualities Investment: Double distribution network system	▪ Raw water quality (location, upstream disposal waste water, salt) and insufficient treatment ▪ Customers opinion	WQ (3rd, AVB, GEO) TECH CUST	EX
± 1915	Search for and switch to alternative source	Water quality (high salt content river Vecht)	WQ	EX
± 1920 1920s	Occurrence: Repeated switching between Vecht and Merwede source water Investment: Research possibilities for alternative sources	Source water quality	WQ AVB	EX
1928	Acquire land for drinking water treating purposes	▪ Search for alternative sources ▪ Signals for future activities of other parties	WQ AVB 3rd	TR
1930s	▪ Adaptation of raw water collection ▪ 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 ▪ Increase treatment capacity ▪ Increase storage capacity	▪ Improving water quality and operation ▪ Increasing water demand	WD WQ TECH	IN EX
1940s	Occurrence: Switch back to alternative water source	Contamination of source water by invaders	3rd WQ	EX
1941	Increase of treatment capacity Installation of disinfection unit	▪ Increasing water demand ▪ Meet water quality standards	WD WQ, POL	EX
1950s	▪ Construction of separated drinking water lake ▪ Construction of drinking water canal	▪ Improvement of source water quality and pre-treatment	WQ 3rd	IN

		▪ Increasing pollution of surroundings		
1950s	Occurrence: ▪ Colored water ▪ Algae growth Investment: ▪ Research of ozone application ▪ Improvement of the hydrological properties of lake and canal ▪ Adaptation of pre-treatment (coagulation)	▪ Source water quality ▪ Customer complaints on taste	WQ GEO OP CUST	EX
1950s-1960s	Research for alternative sources	Expected increase of water demand	WD	EX
>1960	Occurrence: Quality improvement of raw water	Waste water treatment	3rd POL	EX
1977	Rebuilt treatment facility and break-down of former facility. New facility is expanded with ozonation, coagulation, optional dosing of powdered activated carbon. Pre-treatment filters got covered.	▪ Asset condition ▪ Improve drinking water quality water (customers, decree, public health) ▪ New technological insights ▪ Prevent freezing	RNV WQ (CUST, POL) TECH GEO	EX
± 1982	▪ Adaptation pre-treatment (separate coagulation step) ▪ Construction of alternative raw water intake	▪ Improve lake water quality ▪ Alternative source for expected capacity increase	WQ 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) ▪ New technological insights	WQ TECH	EX
1980s	Activated carbon filtration	Continuous improving of analyzing devices	TECH	TR
1990s	Constant improvement of ozonation	▪ Public health ▪ Water quality standards ▪ Microbiological contamination of source water	WQ POL GEO	EX
<1960 – 1990s	▪ Redundant capacity pre-treatment filters ▪ Spatial planning and outline Weesperkarspel ▪ Environmental impact assessments ▪ Research of ultrafiltration applications ▪ Reservations for additional drinking water lake	Expected increase of water demand	WD	EX
Other investments				
1980s	▪ Installation of activated carbon ▪ Shut-down groundwater production facility	▪ Water quality (pollution) ▪ Small scale	WQ 3rd €	EX IN

± 2000	Doubled piping systems	▪ Public health (water quality) ▪ Government forced stopping of household water activities	WQ POL	EX
>1960	Reconstruct transport pipeline	Spatial development of airport	3rd	EX
1999	Install water meters	Political decision?	POL	TR
	▪ Reduce pressure in network ▪ Design of low pressure drop equipment	▪ Save energy ▪ Increase asset lifespan		

13.6 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.

13.6.1 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 18 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 19 presents the relative occurrence rates of the drivers as a percentage.

TABLE 18; 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 19; RELATIVE 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	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.[9]
- 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:

- 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[10] since the 1990s.

[9] 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.

[10] 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.

- 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.

13.6.2 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.

13.6.3 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 the data of three periods of at least 25 years (paragraph 13.6.1), and it is suggested to at least analyse a period of halve a century to identify trends or differences in the occurrence of drivers.

13.6.4 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 32 and Figure 33 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 16 and Table 17, 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 32; OVERVIEW OF MOST IMPORTANT CHANGES IN THE INFRASTRUCTURAL DRINKING WATER SYSTEM OF URBAN AREA OF AMSTERDAM (TAKEN FROM TABLE 17).

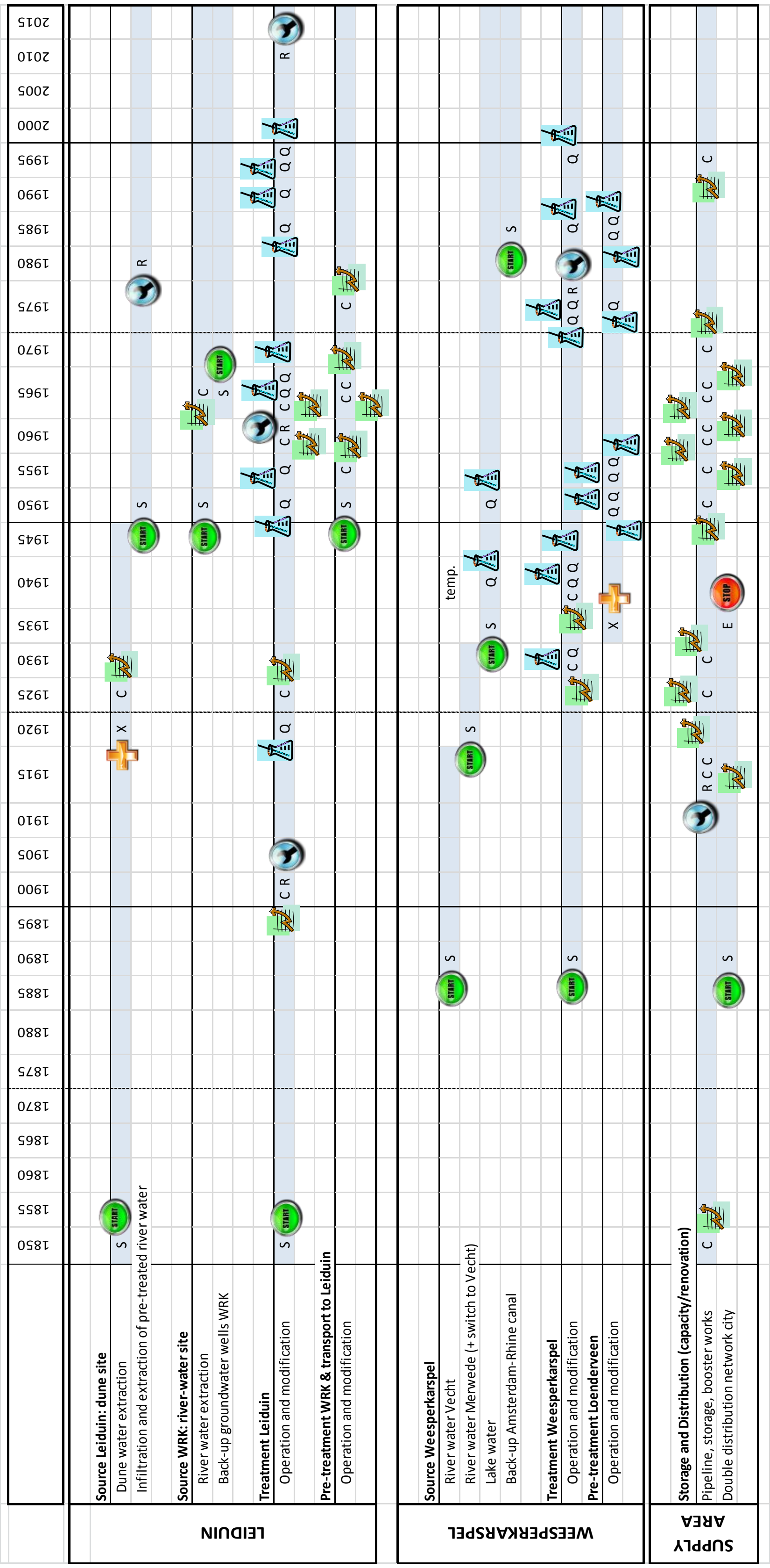
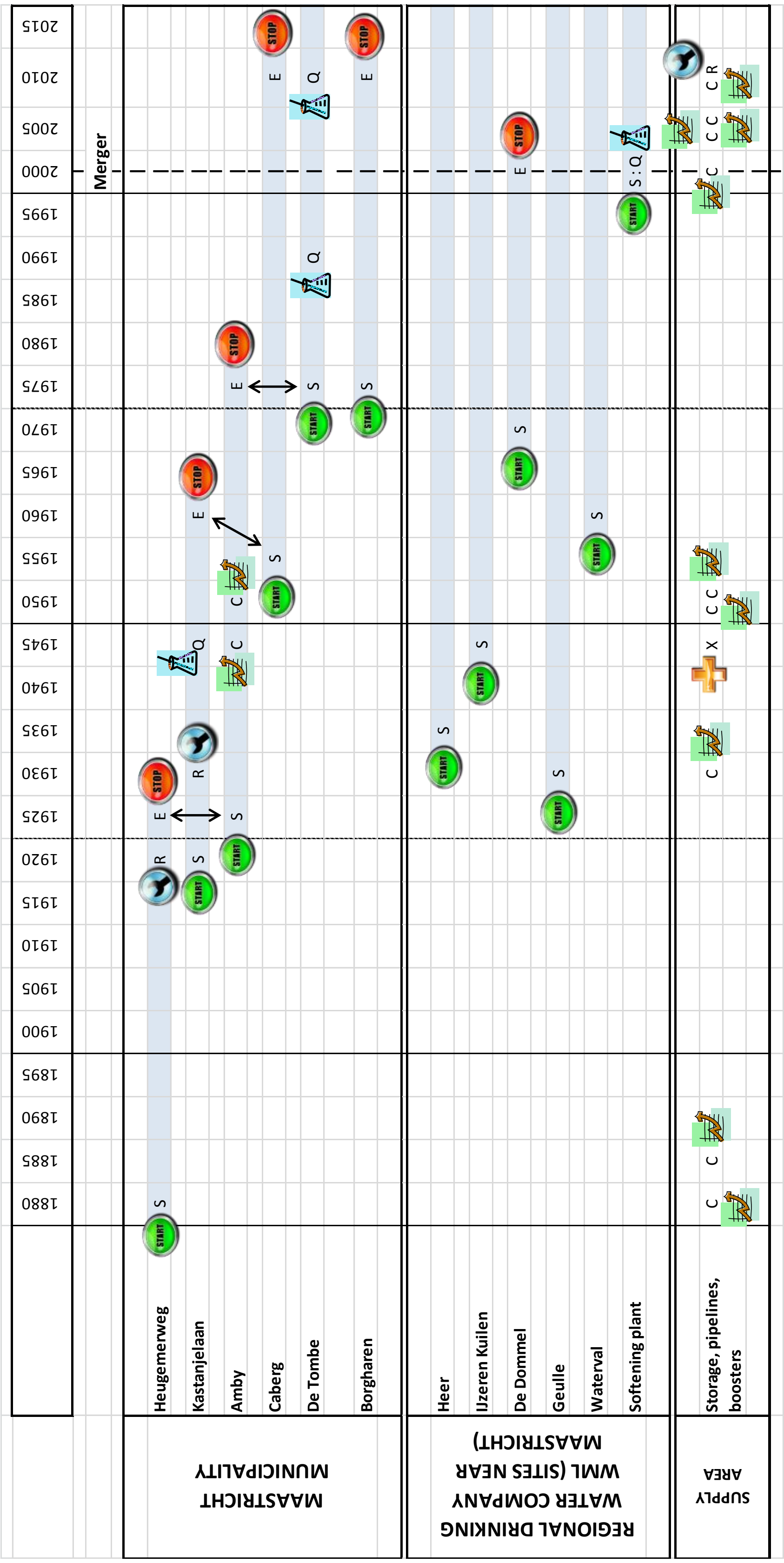


FIGURE 33; OVERVIEW OF MOST IMPORTANT CHANGES IN THE INFRASTRUCTURAL DRINKING WATER SYSTEM OF URBAN AREA OF MAASTRICHT (TAKEN FROM TABLE 16).



The identified investments are presented in a cumulative way over time for all four cities in Figure 34. 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.

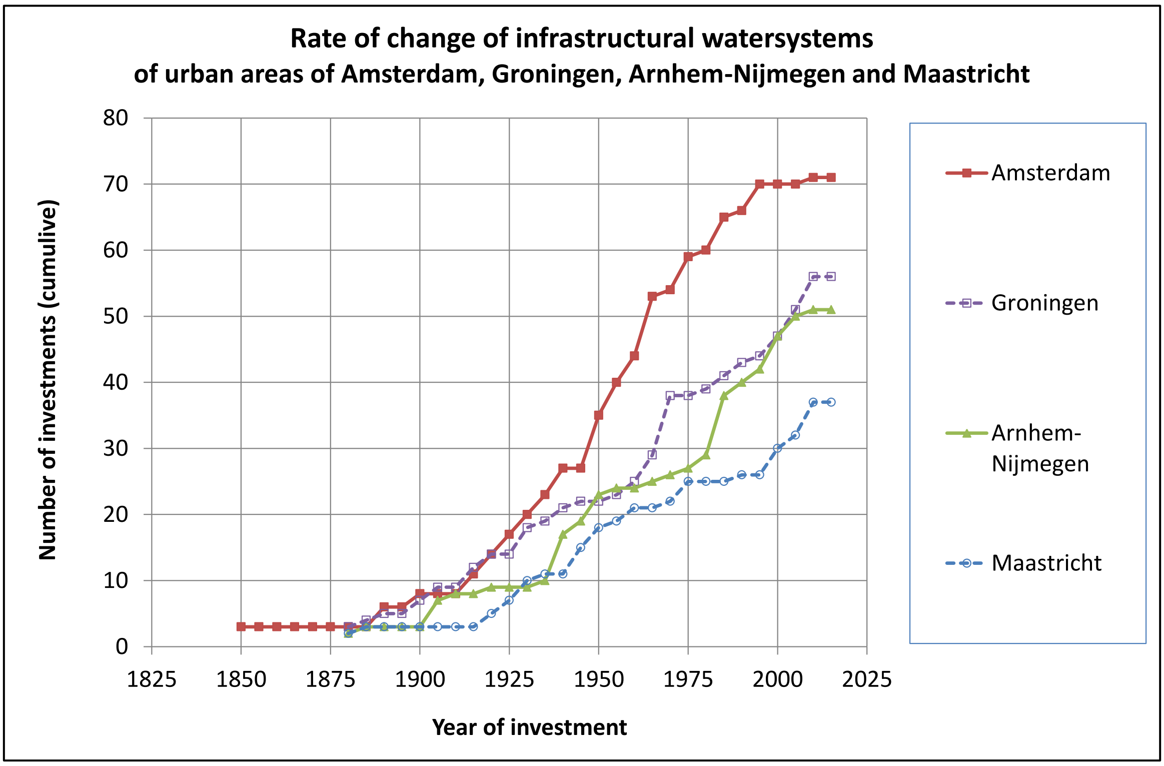


FIGURE 34; RATE OF CHANGE OF INFRASTRUCTURAL DRINKING WATER SYSTEMS OF THE URBAN AREAS OF AMSTERDAM, GRONINGEN, ARNHEM-NIJMEGEN AND MAASTRICHT INDICATED BY THE CUMULATED NUMBER OF INVESTMENTS / OCCURENCES (MOST IMPORTANT INVESTMENTS TAKEN FROM TABLE 14 - TABLE 17.

Figure 32 - Figure 34 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)[11].

13.6.5 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.

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

[11] 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.

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 18 and Table 19):

- 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.

13.7 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.

13.7.1 Semi-quantitative analysis

Table 20 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 20; 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.

13.7.2 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.

13.8 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.

13.9 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

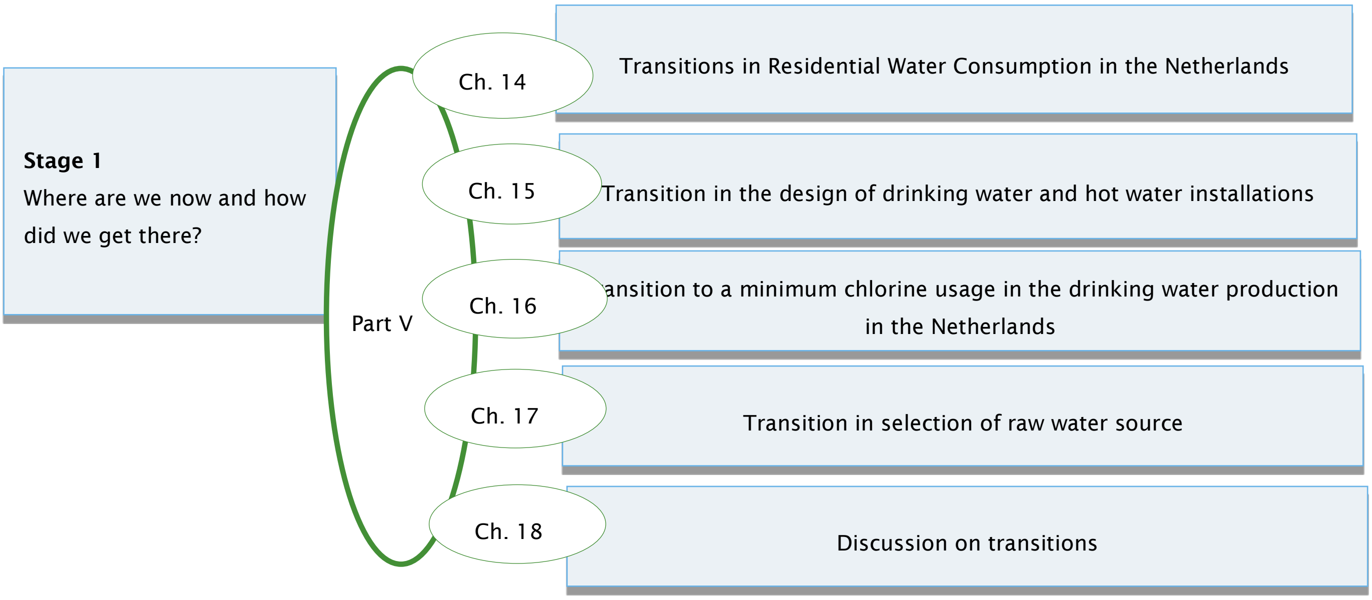
There are also drivers known to have led to investments which have not appeared in the literature review or interviews. An example is the BEEL (Beoordeling Externe Effecten Leidingen) method, used for the assessment of pipelines imposing risks to critical third party's assets in case of pipeline failure.

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.

Part V

Transitions in the drinking water infrastructure – a retrospective analysis from source to tap

The following part of the research, and the accompanying chapters, will be described in Part V:



14 Transitions in Residential Water Consumption in the Netherlands[12]

14.1 Introduction

The objective of this chapter is to gain insight into the dynamics of residential water consumption in the Netherlands since 1900. Understanding the links between the physical and technological features of water systems on the one hand, and society and various types of actors on the other, can provide key information about how urban water transitions occur. The data presented in this chapter draws on a wide range of sources. One major source of information is the Dutch association of drinking water companies VEWIN. Since 1992, VEWIN has commissioned surveys of domestic water consumption every three years. These surveys report the residential water consumption and the penetration of different technologies and appliances (Foekema and Lenselink 1999; Foekema and Engelsma 2001; Foekema, Duijser et al. 2004; Foekema, van Thiel et al. 2008; Foekema and van Thiel 2011 and van Thiel 2014).

For the Netherlands, total water consumption per capita and residential water consumption is well documented, see Figure 35. Not only changes in the total demand have taken place, but also the water use per activity, Figure 11. To understand the changes in demand per activity, Figure 37 shows the overview of adoption of several water appliances in Dutch households between 1947 and 2013. Adoption of toilets, showers and washing machines are successful transitions, reaching (almost) 100% penetration. Penetration of showers and washing machines shows the “S” shape described in Figure 6a. Baths penetration showed a “lock-in” from the 1990s until 2010 and in the last survey a drop on the penetration was reported, this may lead to a back-lash or a stabilization at a lower penetration, (Figure 37). While dishwashers had an acceleration period from 1992 until 2001, after that a “lock-in” period of years and in the last two surveys a small increment in the penetration was reported, which shows a stabilization of the diffusion.

From 1900 until now, different factors have influenced water use at the household level. We describe the transitions in demand in three periods: first a period of low water consumption, lasting until 1960; a second period from 1960 to 1990 in which daily per capita consumption increased from 80 to 130 litres; and a third period from 1990 until 2013, during which per capita daily consumption increased to a peak of 135 lpc in 1995, after which a gradual decrease took place, until 119 lpc in 2013. In the following sub-sections transitions on water demand are described in three periods of time.

[12] Partly based on: C. M. Agudelo-Vera, E. J. M. Blokker, C. H. Büscher and J. H. G. Vreeburg. 2014, Analysing the dynamics of transitions in residential water consumption in the Netherlands.

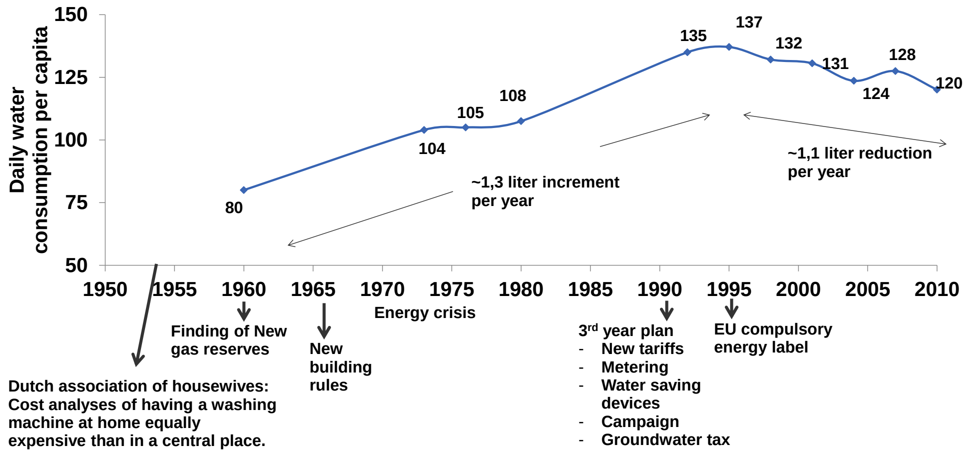


FIGURE 35 OVERVIEW OF THE CHANGES IN THE TOTAL AND RESIDENTIAL WATER CONSUMPTION PER PERSON PER YEAR, IN THE NETHERLANDS AND THE MAIN DRIVERS

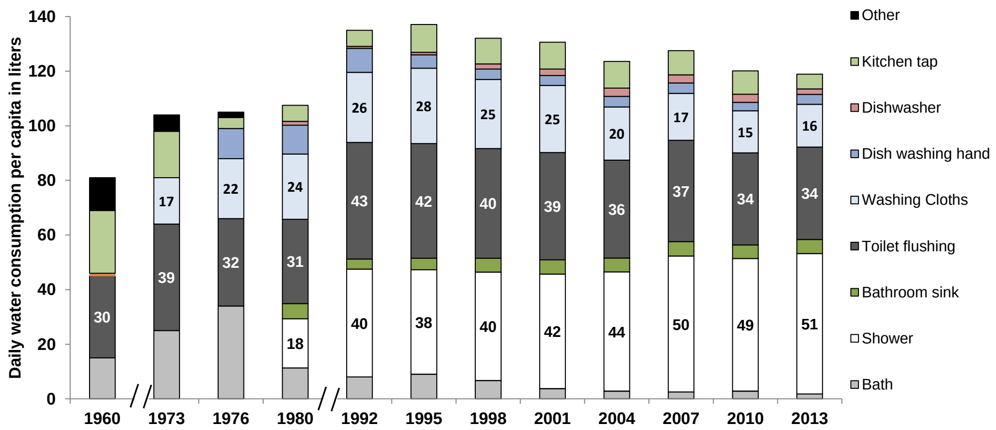


FIGURE 36 RESIDENTIAL WATER CONSUMPTION PER CAPITA SINCE 1960, SOURCES: (CCD 1967; CUWVO/STORA 1976; STORA 1980; FOEKEMA AND ENGELSMA 2001; FOEKEMA, DUIJSER ET AL. 2004; KANNE 2005; FOEKEMA, VAN THIEL ET AL. 2008; FOEKEMA AND VAN THIEL 2011; VAN THIEL 2014; DE MOEL, VERBERK ET AL. 2012)

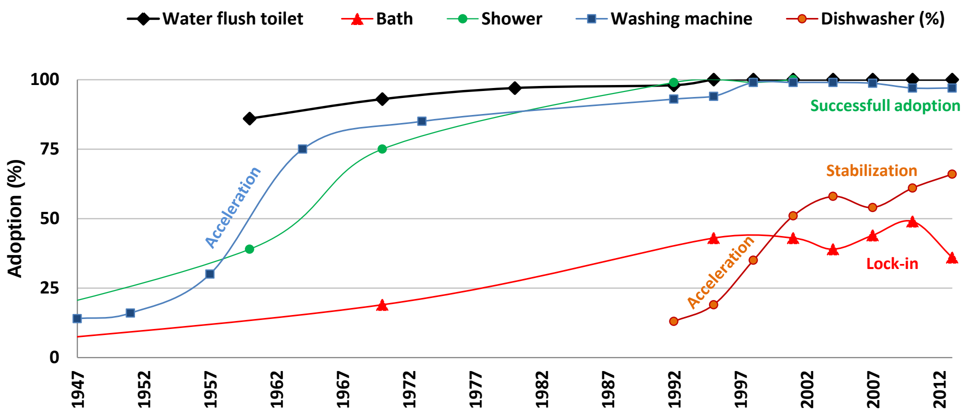


FIGURE 37 OVERVIEW OF THE ADOPTION OF RESIDENTIAL WATER APPLIANCES

From 1900 to 1960 – Increasing of water supply coverage and slow introduction of showers

In 1901, with the Dutch Housing Act, installation of a toilet in each household became compulsory. Showers started to be installed in the 1930s. However, introduction of showers was limited due to lack of hot water supply. In 1933 there was an attempt to make the installation of warm water compulsory but estimates showed that the price of the house would increase by 20% (Overbeeke 2001), which was not affordable at that time. The shower was first mentioned in a national guideline in 1940, where it was stated that bathing was a necessary provision in the home and a bathroom should have at least 1.5 m^2 with a shower or bath and a sink. Hot water was needed to encourage the residents to bathe but high prices were still a barrier. The majority of households did not feel the urgency to adapt to the new technology and kept using cold water only. The Housing Census of 1956 reported that nearly 30% of the households - 750,000 - had a separate bath or shower. However, the majority of the population took a shower or a bath in public baths.

In some cities, housing corporations and energy companies took action to accelerate the market penetration of gas appliances. For instance, in Maastricht, the municipal gas company came in the 1950s with a new, attractive hire and purchase (lease) scheme for geysers. The gas company could purchase and finance the installation of a geyser, including faucets and showerheads, and the tenant would pay back the costs in sixty monthly instalments to the gas company.

By 1951, the percentage of population connected to piped water had risen to 82.4% (Vogelzang, 1956). In rural areas this percentage was much lower, Table 21. In the 1950's, also new actors appeared. Two intermediary organizations were found to assist consumers: The Dutch household council (Nederlandse Huishoudraad) and the Consumer association (Consumentenbond). These organizations provided independent and objective advice and information to the customers, playing an important role in the transition towards modern households. Washing machine penetration in Dutch households was supported by the Dutch association of housewives - "De Nederlandse Vereniging van Huisvrouwen". In 1954, a cost comparison showed that washing clothes at home was comparable to the costs in a central laundry facility. The introduction of washing machines and the more spacious bathrooms or separate washing rooms changed household routines, because women preferred to wash clothes at home. In 1957 the Drinking Water Law was enacted by the Dutch government. This was the beginning of the involvement of the Dutch government and the EU in laws and regulation concerning the drinking water supply.

TABLE 21 PERCENTAGE OF POPULATION IN DUTCH PROVINCES CONNECTED TO PIPED WATERWORKS IN 1951(VOGELZANG, 1956)

Province	%	Province	%
Groningen	72	North Holland	99
Friesland	60	South Holland	98
Drente	37	Zeeland	81
Overijssel	75	North Brabant	76
Gelderland	60	Limburg	72
Utrecht	93		

1960-1990 The Netherlands as gas economy – modernizing the household

In the 1960s, a period characterized by rapid growth, prosperity and social changes began, driven by the discovery of large quantities of natural gas in Groningen. The decision of the oil companies and the Dutch government to use gas for heating of buildings brought the desired comfort. The introduction of natural gas was a spectacular innovation, because almost all Dutch households started to use natural gas within a few years. For the gas companies, the further adoption of geysers was of great importance to increase their sales. In the years 1965 and

1966, gas prices for heating were set low. In 1968, 78% of homes had a gas connection. The intention of the Gasunie[13] and the local distribution was to connect as many households as possible, including rural areas. The natural gas coverage rose rapidly to 89% in 1975 and further to 97% in 1980. Not only the number of connections, but also the average annual use per home rose largely. The main reasons for this was the increasing use of gas for stoves and central heating and the increasing use of warm water for shower and bath.

Gas availability pushed the development of new appliances and new niches. There was a large-scale information campaign to convince users to switch to natural gas for heating. Information on pricing was an important component. Information was not only targeted to consumers, but also to architects, contractors, installers and landlords (local authorities, housing associations, etc.). Different media were used, including newspapers, magazines and from 1968 also television. Additionally, gas companies gave verbal information through lectures and visit customers at home. Consumers' need for comfort and luxury also grew. Low gas prices enabled the acceleration on the adoption of domestic water heaters. This led to changes in society, in two ways. First, in the mid-1960s, warm water was no longer seen as luxurious. Second, by 1970, adoption of showers reached 75% and 97% of the new houses had warm water and a shower or a bath. Adoption of showers implied changes in routines, this is seen by the "lock-in" of the adoption of bathtubs, Figure 37. Other changes in the drinking water regime due to the diffusion of water heaters are at policy level. In the 1960's, building guidelines had to be revised to meet the needs of the new appliances. By 1965 the new guidelines 'Model Bouw Verordening' en 'Voorschriften en Wenken' increased the area of the rooms and the houses due to the modernization of the household (Liebregts 2011). The 1970's and 1980's witness an accelerated diffusion of use of water consuming appliances. Daily water consumption per person grew from 80 lcd in 1960 to 108 lcd in 1980, a 35% increment in two decades.

The price of natural gas price for households rose sharply between the early 1970s and 1985 – the first energy crisis. During this period the real price increased (taking inflation into account) with 135%. The average household gas consumption for heating decreased from 2800 m^3 in 1980 to 1800 m^3 in 1990 due to better insulated buildings and more efficient heating systems, which were driven partly by cost. Contrary to heating, energy consumption for hot water supply certainly did not decline since the energy crisis of 1973. On the one hand, the rise of the bath penetration and frequency slowed in the 1970s and saved energy because many households have a water-saving shower head. On the other hand, people nowadays take a shower or bath more often than in the 1970s as a result of increased standards of personal hygiene. Parallel, more bathrooms were built with a bathtub due to the rise of prosperity, not having a direct effect on hot water consumption (Overbeeke 2001), which was estimated at 15 litres per person per day (water at 60 º C) in 1970 (Naarding et al. 1970). During this period, the availability of energy (gas) was a main driver to increase the water demand. Gas availability influenced changes in the regime at first by increasing standards of comfort and in the long run by influencing building codes.

1990 – Now: More efficient water use

The residential water consumption had a peak in 1995, and since then a slow downward trend in per capita household water consumption took place,

Figure 11. In 1991 the third 10 year plan of the government was established. Within the action plan six measures were described: i) intensification of information activities; ii) introduction of a new water tariff system (integrated water rate) for households; iii) penetration of 100% individual metering; iv) prescription of the application of water saving devices in construction; v) product testing and information via labels and vi) the tax on groundwater abstraction. Household water costs increased in the 1990s above the inflation rate: on average by 3% annually for

[13] Gasunie is a Dutch gas infrastructure company

the supply of potable water (Krozer et al. 2010).The taxes that were implemented from 1995 onwards, provided extra incentives for water saving measures (CBS 2012).

To slow down the increasing water use, different initiatives were implemented. VEWIN started the campaign "Be wise with water" and to slow down the increasing hot water use, the National Consultation Platform for Hot Water[14] was formed. In 1994 guidelines for drinking water systems in households[15] were published considering the reduction of water and energy consumption and the consequences for the design of drinking water systems. In 1995 the government, water companies, energy companies and other relevant market parties signed a cooperation declaration Approach for Hot Water Conservation[16]. In 1997 European legislation made energy labelling mandatory for washing machines, and for dish washers in 1999, which specifies the energy and water consumption of an appliance and grades overall energy performance. As a consequence, the average consumption per washing load of washing machines is almost halved starting from 100 litres in 1992, Figure 38a. Most of the energy consumption of washing machines is for heating water, thus less water per cycle means lower energy use. Furthermore, new European norms of sanitary fixtures were developed that take specific water consumption into account, e.g. NEN-EN 1112 of 1997. Energy efficiency has been a constant driver in the last two decades, as shown in the transition towards more energy-efficient systems to heat water, for both heating the home and heating tap water, Figure 38b. This transition has been supported by technological developments while comfort and user behaviour were not affected.

In the 1990s environmental concern triggered innovation and niches were created. In 1996, nine pilot projects were defined to study the possibilities of alternative sources of water, such as rain water and grey water for non-potable use. However, in 2003, the ministry banned all dual water supply schemes for households in the Netherlands, after health problems in one of the projects were proven due to a wrong connection between the drinking water supply and the recycling network (Correljé and Schuetza 2012). This is an example of a backlash trajectory, (Figure 6).

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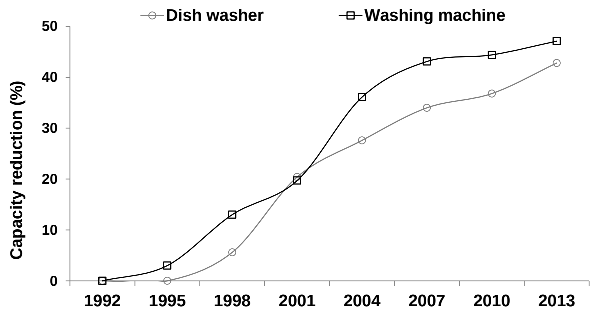
[14] Nationaal Overlegplatform Warmwater. OWW has respresentants of EnergieNed, EZ, Gasunie, GASTEC, KIWA, Novem, VEDIB, VEWIN, VFK, VNI and VROM.

[15] ISSO - 30 Tapwaterinstallaties in woningen

[16] Aanpak Warmwaterbesparing

a)



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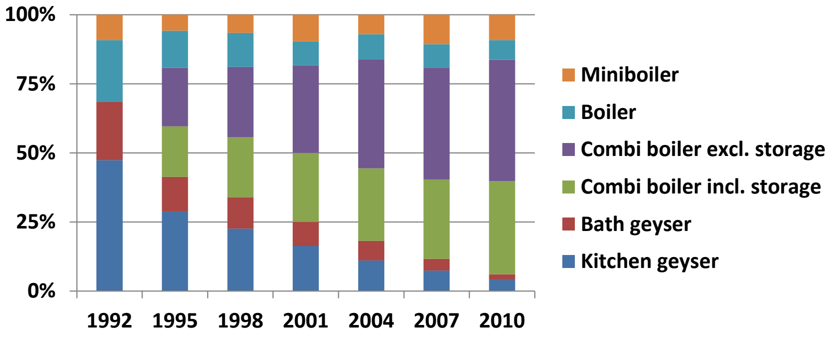

FIGURE 38 TRANSITION TOWARDS MORE EFFICIENT ENERGY EFFICIENT APPLIANCES IN THE LAST TWO DECADES A) REDUCTION OF THE CAPACITY OF WASHING MACHINE AND DISHWASHER MACHINE, B) TRANSITION OF THE MARKET PENETRATION OF DIFFERENT HOT WATER SYSTEMS AT RESIDENTIAL LEVEL.

14.2 Analysing the transitions

During 1940-1960 the housing shortage, economic problems that resulted from WWII and reconstruction were a barrier for diffusion of innovations. The breakthrough of novelties, such as showers and washing machines in mainstream markets triggered disruptions and a (relatively) rapid regime change. In the case of showers, this was strongly influenced by gas availability that made warm water use affordable. Regimes describe the behaviour of actors that are part of communities. Regimes change more gradually and over a longer period of time, in response to outside pressures or changes in the system. During this period decisions made by gas companies, households and other actors were decisive for the subsequent developments. For instance, women associations and energy providers had a big influence on the changes and modernization of the households during the 1960s till the 1990s. Changes in the socio-technical system – changes in routines and comfort demands - drove changes in the norms, e.g., changes in the building code were needed to make room for the shower and the washing machine. Changes in the building code, reinforced further market penetration of shower and washing machines, which is often called a reinforcing loop.

This analysis shows that there are large differences on the penetration trajectories for different water appliances. Full penetration of showers took approximately 60 years. Diffusion of showers increased by 4% per year from 1960 to 1970, after that the average rate declined to 1% per year. The fastest penetration growth – 6.4% annually – was found for washing machines between 1957 and 1964. Dish washers also showed a fast penetration rate (5.3% per year between 1995–2001). However, this penetration stagnated around 60%. During the last 15 years technological development has resulted in more efficient appliances. The capacity reduction of washing machines was driven by energy efficient requirements; most of the energy consumption of washing machines is mainly for the heating of water, less water per cycle means less energy use. A balancing loop is for instance, the energy labelling of appliances and buildings, which have led to a reduction of the water consumption. Another balancing or reinforcing loop are the changes in routines e.g. decrease of bathing and the increase of showering, with increasing comfort and hygienic standards. Measures such as labelling parallel to more conscious water users led to adjustments in regulative, normative, and cognitive aspects of regimes.

Changes in water demand are the result of interactions between the adoption of new technologies in combination with changes in technology and changes in user behaviour. The interactions of these three factors have led to an increment in the residential water demand, with a peak in 1995, and afterwards stabilization of the consumption. Although at first, transitions after the 1990s can be logically related to technological development such as water saving devices and awareness campaigns such us “Be wise with water”, when looking at a broader scale, European regulations have been a catalyst, which speeded the transition towards regime reorganization.

Drinkwater consumption is determined by the availability or adoption degree of the water appliances, the flow rate and the duration of use, which determine the volume per use and the frequency of use. With increasing welfare and good organisation, the availability increases. For instance, gas availability fostered warm water use, which lead to an increase in the frequency and in the duration of the shower. Similar dynamics are observed for washing machine, dishwasher, etc. Flow rate and volume are determined by the available technology. Frequency and duration is determined by culture and possibly by cost. These factors are dynamic, and at certain point in time can reinforce or balance each other. For instance, higher adoption degree can be counteracted by appliances with a lower flow rate.

Figure 39 shows the dynamics involved in daily water consumption for shower, which, according to Figure 11, was approximately 40 lcp in the 1990s and in the last decade is approximately 50 lcp. Figure 39 shows the dynamics that are involved in the daily water consumption for shower from 1992. Two main variables are involved: *i*) water use per shower (Figure 39a) and ii) frequency, (Figure 39c). Water use per shower is the result of the average shower duration (culture), which in the last decade has increased almost one minute. Another factor is the shower average capacity, determined by available technologies, which has been relatively stable since 1992 (Figure 39b). Although, shower average capacity seems rather stable, technology transition is constantly taking place. Figure 39b shows the acceleration of penetration of water saving showers from 1992 until 2002. Thereafter water saving shower heads show a lock-in. In the last decade a new appliance, a “luxurious shower”, which has started to be adopted by Dutch households. A luxurious shower consumes in average the double of a conventional shower head (14.4 l/min). Currently the penetration rate of luxurious showers is 4%, which means that it has overcome the “innovators” phase and it is in the “early adopters” phase, Figure 6.

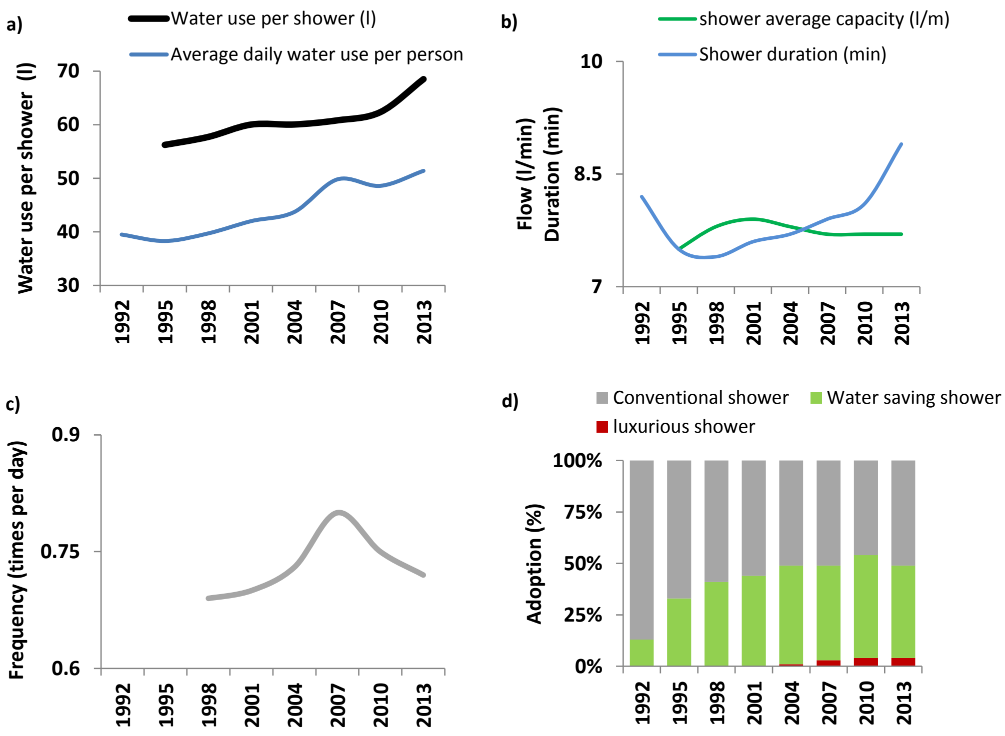

FIGURE 39 TRANSITION TOWARDS MORE EFFICIENT ENERGY EFFICIENT APPLIANCES IN THE LAST TWO DECADES A) REDUCTION OF THE CAPACITY OF WASHING MACHINE AND DISHWASHER MACHINE, B) TRANSITION OF THE MARKET PENETRATION OF DIFFERENT HOT WATER SYSTEMS AT RESIDENTIAL LEVEL.

Another example of changes in demand due to diffusion of technology is the adoption of water saving toilets. In this case, frequency of use cannot be influenced, but technology improvements have reduced water consumption per capita from 42 lcp in 1992 to 34 in 2013. Water saving toilets are still in the acceleration phase with a current penetration of 80%, Figure 40.

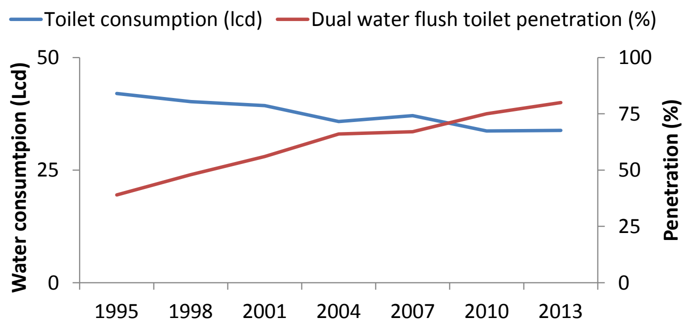

FIGURE 40 DAILY WATER CONSUMPTION PER CAPITA FOR TOILET FLUSHING AND DIFFUSION OF WATER SAVING TOILETS (DUAL WATER FLUSH).

The water-energy interaction – which is recently gaining attention – showed to be present since the modernization of households. The decrease in water demand since 1995 is almost completely technology driven and promoted with the labelling of water saving equipment. Therefore, these developments are important to watch. Water companies can influence these transitions by participating in campaigning and research. This knowledge must be used in water infrastructure planning as it impacts the demand and the typical demand patterns. Our analysis confirmed that, as stated by McDowall (2012), the power required to steer the socio-technical development is diffused through networks of actors, Figure 41. Moreover, the role and influence of the different actors may change over time. Figure 41 shows the main drivers and actors, involved in the residential water demand transitions.

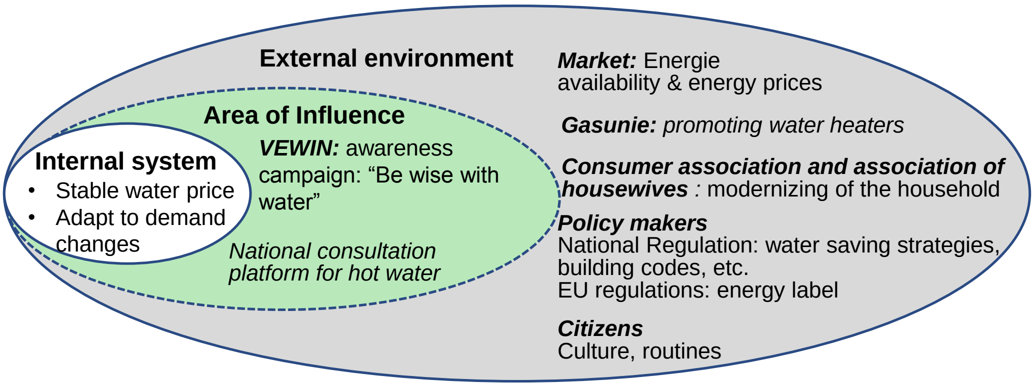

FIGURE 41 SPHERE OF INFLUENCE OF THE TRANSITION IN RESIDENTIAL WATER CONSUMPTION.

14.3 Discussion

Changes in water demand are the result of interactions between the adoption of new technologies in combination with changes on technology efficiency and changes on user behaviour. In the development of residential water demand two main drivers were identified: personal hygiene and energy availability. Personal hygiene can be identified in the penetration of first the flushing toilet, second the installation of baths and showers and finally by penetration of washing facilities for clothes. As a second driver, energy availability has played an important role, first in the period 1960-1990 being gas availability the main driver for hot water supply, leading to changes in comfort perception, routines and in the building codes; and later after the 1990s by playing a role in the reduction of water demand.

Although determining future water demand remains a challenge, we found that adoption of water devices has shown a maximum adoption rate of 6.4% in a year and approximately 10% in a decade. Full adoption of shower took approximately 60 years and 75% adoption of water saving toilets took approximately 40 years.

Additionally, behaviour can be influenced by external drivers, such as, energy prices, however until now these effects seem to be of short duration. By monitoring different trends in the SEPTED variables adaptive forecasting of the demand. Hygiene and energy availability were the main drivers of changes in water use. In the 1960s they reinforce each other, energy availability accelerate shower penetration and campaigns to increase hygienic practices increase the frequency of showering leading to an increase of water use. The decrease in water use since 1995: almost completely technology driven and promoted with the labelling of water saving equipment. After 1990s, energy did not completely affect directly users behaviour, but development of more efficient washing machines and dishwashers did. Additionally, more efficient water heaters have also influenced the residential water use. Technologic development is not only the only driver, awareness campaigns, and factors such as wealth (f(comfort), have a large influence in residential water use.

Although, culture is more difficult to change, analysing a few decades, changes in routines and perception are found. Active influence has been tried, and it remains difficult, however it does not mean that water companies have to accommodate and adapt to constant changes in demand. Technology developments can be supported by new “stronger” policies or by developing new niches of innovations. Water use can be influenced by changes in energy prices.

This case shows that water demand is driven by different SEPTED dimensions. Different stakeholders within the sphere of influence. In the past water companies have accepted the changes in demand and have been willing to cater for it, being the steering role of water companies limited.

14.4 Conclusions

The residential water demand in the Netherlands has been largely influenced by three main activities: toilet flushing, showering, washing machine. The rate of the change per activity is relatively slow with a maximum changing rate of 10% in a decade. However, simultaneous adaptation of shower heads and washing machines resulted in a significant increase of the water demand in the 1970s and 1980s. Later, the adaptation of the water saving toilets and shower heads lead to a significant reduction on the water demand in the 1990s.

Monitoring the demand requires understanding of the relationships of each activity: flow, duration and frequency. As shown in the historical review, there is room for the drinking water companies to steer the changes by supporting technology development, by communicating with the customer. These strategies to influence users behaviour have to consider the external environment, for instance, economic development which may lead to increase need for comfort.

Given the complexity of the evolution of the water demand, it is required to identify the different stakeholders involved in order to be able to steer a given transition path. Additionally, by identifying the “trends” of the external environment, water companies can prepare for changes that are outside their sphere of influence.

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15 Transition in the design of drinking water and hot water installations

15.1 Introduction

In recent years the attention given to the water-energy nexus has grown. Although insight into the energy needed to run our water systems has gained, little is known about the water-energy nexus at the building level, specifically, regarding hot water use. Reference to hot water use is often not reported. In 1970, hot water consumption was estimated at 15 litres per person per day (l/pd). Currently it is estimated that a person uses about 60 l/d of hot water of 40° - 60°C, for personal cleaning and kitchen use. Additionally, 13 l/pd of hot water is heated in the washing machine and dishwasher (Blokker et al., 2013).

Despite all the changes in appliances and increasing hot water use, described in Chapter 14, Dutch guidelines on the design of drinking water installations for non-residential buildings were, until recently, based on measurements carried out between 1976 and 1980 and there were no guidelines for predicting hot water use. As a result, suppliers of heating systems use company specific guidelines. Figure 10 shows an overview of the use of guidelines for the design of water systems in the Netherlands for residential and non-residential buildings (Agudelo-Vera et al., 2014). In 2002, the old approach was no longer deemed suitable for the current situation due to the increasing range of available appliances in the market and to the changes in people's behaviour. In general, old guidelines overestimated the peak demand values. These peak values are crucial for the optimal design of the water system. Badly designed systems are not only less efficient and therefore more expensive, but can also cause stagnant water, possibly leading to increasing health risks.

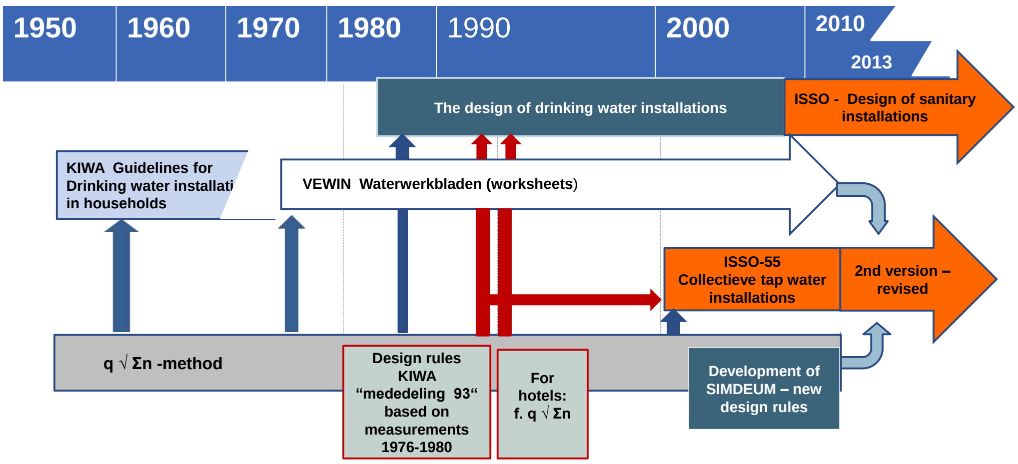


FIGURE 42 OVERVIEW OF AVAILABLE METHODS AND GUIDELINES IN THE NETHERLANDS.

Since 2002 KWR Watercylce Research Institute and the Dutch installation sector (Uneto-VNI, TVVL and ISSO) worked on developing new design rules for non-residential buildings not based on measurements, but based on simulations. The new design-demand equations have been adopted in a revised version of the Dutch guidelines, which were released in 2013. In this chapter, we describe the transition in the design of drinking water installations.

15.2 Transition towards new guidelines for efficient water-energy design at the building level

Late 1940s – early 2000s

In the late 1970s, it was found that the "new" dangerous Legionella bacteria could grow in warm water. It was only after 1999, after a catastrophic outbreak, that strict regulations for Legionella prevention in drinking water were introduced in The Netherlands. Audits of water companies made clear that a lot of drinking water installations were not safe enough. The need for safe and reliable (hot) water systems was recognized, giving a boost to the development of new insights into the design and implementation of hot water installations. In 2001, guidelines for drinking water installation for buildings ISSO-55 were published, in which (hot) water use was still based on old measurements and calculation methods.

Understanding hot water demand is essential to select the correct type of water heater as well as the design capacity of the hot water device. For a proper design of (hot) water systems, the instantaneous peak demand or maximum momentary flow (MMF_{cold}), the peak demand of hot water, i.e. MMF_{hot} and the hot water use (HWU) – in several time steps - need to be determined. A reliable estimation of these values for an arbitrary building (type and size) by on-site measuring would require an intensive and expensive measuring campaign and would consume a lot of time. Therefore, in 2003, the water companies and the installation sector (TVVL / Uneto - VNI) commissioned KWR Watercylce Research Institute to investigate the possibilities of simulating the (hot) water demand patterns.

Simulating cold and hot water use patterns

In the late 2000s, KWR developed a software tool to simulate cold and hot water use patterns called SIMDEUM. SIMDEUM stands for "SIMulation of water Demand, an End-Use Model." It is a stochastic model based on statistical information of water appliances and users (Blokker et al., 2010). SIMDEUM models water use based on people's behaviour, taking into account the differences in installation and water-using appliances. This means that in each building, whether it is residential or non-residential, the characteristics of the present water-using appliances and taps (i.e. flow rate, duration of use, frequency of use and the desired temperature) are considered as well as the water-using behaviour of the users who are present (i.e. presence, time of use, frequency of use), see Figure 43. With this tool, customize calculation of the peaks required for an optimal design of water installations was possible.

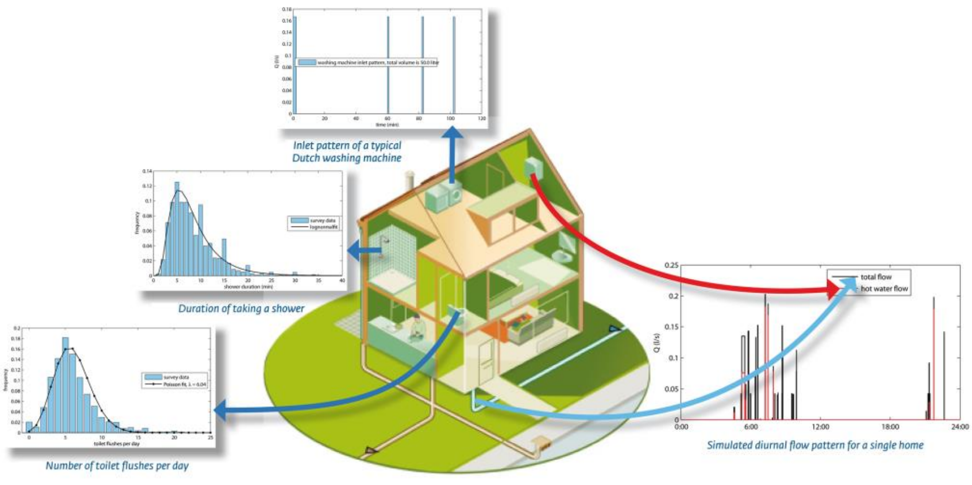


FIGURE 43 SCHEMATIC REPRESENTATION OF THE SIMULATIONS WITH SIMDEUM

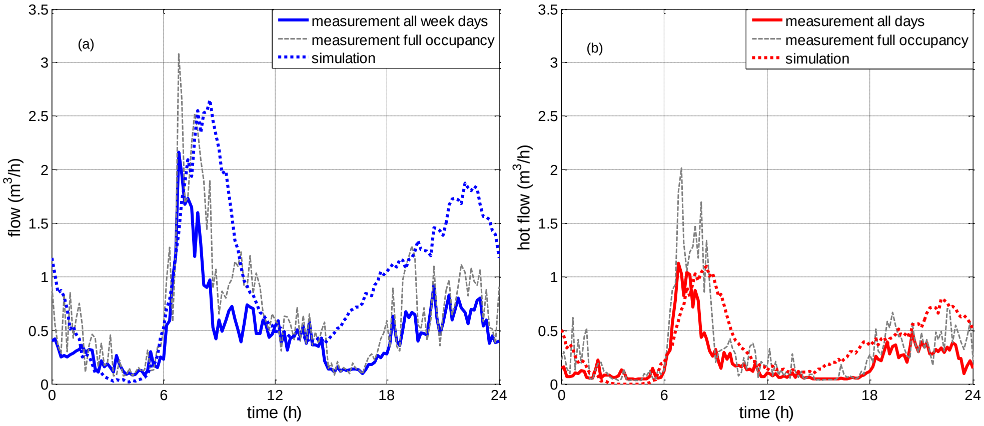
Deriving new design rules using "design-demand equations"

In 2010, a procedure was developed to derive design-demand equations for the peak demand values of both cold and hot water for various types of non-residential buildings using SIMDEUM. SIMDEUM for non-residential water demand follows a modular approach. Each building is composed of functional rooms, characterised by its typical users and water-using appliances. The characteristics of the users and the appliances are different for each type of building are described in Blokker et al., 2010 and Blokker et al., 2011. Different categories were researched viz. office, hotel, nursing homes. Within each category different typologies were defined. The typologies vary in types of appliances, like types of toilets, flow of showers, and in the type of users, like business or tourist hotel guests.

With this approach, water demand patterns over the day for cold and hot water demand were simulated for a specific building. From these daily water demand patterns, the characteristic peak demand values of cold and hot water during various time steps were derived. These peak demand values and the HWU for several buildings could be described by simple linear relations as a function of the dominant variable[17]. These linear relations form the design-demand equations. The aim of the design-demand equations is to predict the peak demand values (MMF_{cold}, MMF_{hot} and HWU in different time periods) for various types and sizes of buildings.

Test and validation of the "design-demand equations"

The validation of the new design rules was performed in two steps. The first step focused on validating the assumptions of how to standardize the buildings, using the functional rooms. This was done with measurements and surveys. Cold and hot water diurnal demand patterns were measured (per second) for three categories of small-scale non-residential buildings, viz. offices, hotels and nursing homes. The surveys gave information on the number and characteristics of users and appliances, and on the behaviour of the users, like the frequency of toilet use, or the use of the coffee machine. Comparison of the surveys with the standardized buildings showed that the assumptions of the number of users and their water using behaviour as well as the number of appliances correspond with the surveyed buildings. Comparison of the simulated water demand patterns with the measured patterns showed a good correlation. This good correlation indicates that the basis of the design-demand equations, the SIMDEUM simulated standardised buildings, is solid. The results for a business hotel are presented in Figure 44, showing the measured and simulated cold and hot water flow.



[17] The dominant variable for hotels is the number of rooms, which can be occupied by 1 or 2 guests, depending on the type of hotel. For offices it is the number of employees and for nursing homes the number of beds

FIGURE 44 COMPARING AVERAGE MEASURED AND SIMULATED DEMAND OF A) COLD WATER AND B) HOT WATER OF A BUSINESS HOTEL

The second step focused on validating the design-demand equations by comparing the simulated and measured peak flows. For hotels, the derivation of peak demand values from the measured water demand patterns was especially difficult, due to the varying occupation of rooms. However with the proposed method, the MMF_{cold} can be predicted fairly well. Figure 45 shows the comparison of measured and simulated peak flows and compares them with the old guideline (Scheffer, 1994) and with the original q√n-method. The MMF_{cold} and MMF_{hot} can be predicted fairly well. The studies showed that the old guidelines overestimate the MMF_{cold} with 70%-170% for hotels, resulting in oversized heaters.

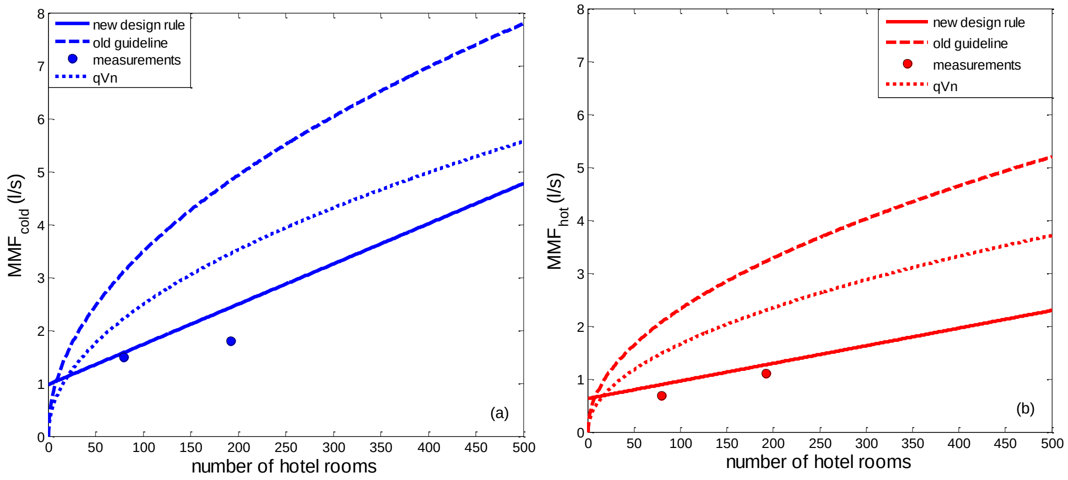


FIGURE 45 COMPARING MEASURED AND SIMULATED PEAK FLOWS A) COLD WATER AND B) HOT WATER OF A BUSINESS HOTEL

Consequences for design of distribution systems and heating system

The new equations lead to a better estimation of the MMF_{cold} than with the old guidelines. Moreover, the pattern of water use of different building types can be easily determined using the functional rooms. The new equations reduce the design of heater capacity with a factor 2 to 4 compared to suppliers proposals, while still meeting the desired need and comfort. Thus, the improved insight of the new design-demand equations will lead to an energy efficient choice of the hot water systems, and thus save energy. Moreover, the smaller design of the heating system reduces the stagnancy of water, which may lead to less hygienic problems.

Detailed insight into water use per functional room was also gained, allowing for a customized design per building. Figure 46 shows the variation of (hot) water consumption per bedroom for a business hotel with two different shower types and for different hotel size. It shows 40-50% of total water use in hotels is heated.

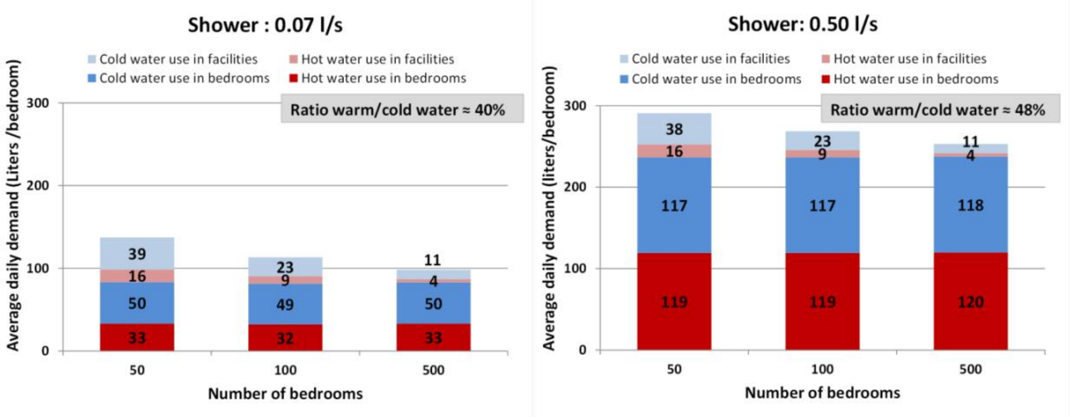


FIGURE 46 VARIATIONS IN THE DAILY WATER USE IN A BUSINESS HOTEL ACCORDING NUMBER OF BEDROOMS. A) FOR A WATER SAVING SHOWER HEAD AND B) FOR A LUXURIOUS SHOWER HEAD.

15.3 Analysing the transition

A key driver to speed up the transitions was the health risk, followed by the willingness of the different stakeholders to steer a transition towards an specific goal, an updated more efficient and save design. With this 10 year study, more insight into the actual (hot) water consumption was gained. Simulating the water demand patterns with SIMDEUM showed to be a reliable method to predict water peaks and daily water patterns, leading to an update in the guidelines for design of hot water systems (ISSO-55. 2013).

Based on the results, new design rules were determined and better understanding of the water and energy nexus at building level according its function was gained. The design rules allow a better choice of the hot water system, resulting in smaller systems using less energy. Additionally, the stagnancy of water is reduced, thus less hygienic problems are expected. In the revised version of the ISSO 55 guidelines, the new design rules based on SIMDEUM are included.

Water-energy nexus at the building level is strong but complex since it is specific for each building type. Moreover, it depends on user behaviour and fixture characteristics, which change over time driven by different factors, from legislation to comfort, as describe in Chapter 3. New flexible approaches such as SIMDEUM, which consider water and energy simultaneously, support the design of more efficient resource use at building level. Although at the beginning, updating the guidelines represented a major challenge, in the long run it represented a win-win-win situation for the customers, the environment and the installation sector. Since 2002 KWR Watercycle Research Institute and the Dutch installation sector (Uneto-VNI, TVVL and ISSO) worked on developing new design rules for non-residential buildings not based on measurements, but based on simulations performed with SIMDEUM. The new design-demand equations have been adopted in a revised version of the Dutch guidelines, which were released in 2013. The Netherlands is a frontrunner, being the only country in the world with specific regulations for water use in non-residential buildings. Therefore, they are a step ahead in the transition to more sustainable buildings.

The integrated approach of this transition, in which water and energy use and health risks are simultaneously considered, highlights the need of cooperation and working together. In this case several stakeholders in the transactional sphere have shared a vision and decided to work together and steer the transition towards updated guidelines. Figure 47 shows the different stakeholders involved in updating the guidelines. This transition took approximately a decade. In this case, new knowledge and new tools were crucial to start and accelerate this transition. The end-use approach of SIMDEUM, allowed simulating and understanding hot water demand for different buildings and the different stakeholders have work together to translate this to practical application in the installation sector.

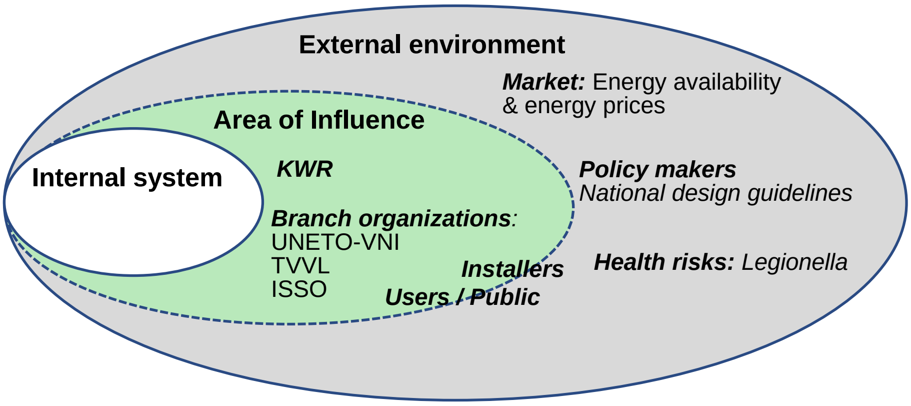


FIGURE 47 SPHERE OF INFLUENCE OF THE TRANSITION TOWARDS NEW DESIGN GUIDELINES FOR HOT WATER INSTALLATIONS.

Guidelines are enforced when there is a need for them. Guidelines are based on state-of-the-art knowledge. For instance, hot water guidelines were needed due to 1) increase gas use and fast adoption of showers. 2) new buildings and new water connections, 3) laws and regulations regarding safety, etc. Due to the changes in the (hot)water use, routines, etc., guidelines become obsolete. Guidelines are adapted when 1) calamities happen (e.g. legionella outbreak), 2) new requirements have to be met (sustainability/energy efficiency, etc) and 3) New knowledge is developed, for instance measurements < n√q or development of SIMDEUM. Nowadays new knowledge is based on research, possibly as a result of calamities or new requirements. Which shows the causality of events in the drinking water infrastructure.

In the Netherlands the revision of the guidelines lead to smaller systems than the ones used in practice and the ones predicted by the old guidelines. This indicates that the common practice leads to oversized systems, with corresponding potential quality problems. The tendency to over dimension the system might also be present in other countries. However, international guidelines do not exist in the public domain. The Netherlands is a front runner in this field.

15.4 Conclusion

This chapter described a transition regarding design guidelines. This type of transition does not follow the same diffusion pattern that the technology but it influenced technology indirectly. The starting point of the transition can be traced to the legionella outbreak in the late 1990s, which called the attention of policy makers and practitioners and fostered research. In this transition two clear drivers can be identified: health risk and energy efficiency, and a catalyser of this transition was the new knowledge and tools.

The main steering stakeholders were the branch organizations. Branch organizations used their sphere of influence steered the transition towards new research resulting in an update of the guidelines. This is a clear bottom-up transition, which shows how the landscape can be influenced from the regime.

This case demonstrate that cooperation in the sphere of influence can lead to changes in the landscape, in this case, by updating existing guidelines. Although initially took more than 50 years to define the first guidelines, the revision and updating of new design guidelines, at national level took place in approximately a decade.
With increasing concern for sustainability, a similar approach can support the development of guidelines for the design of on-site water systems, such as rainwater systems or energy harvesting techniques i.e. harvesting energy from water flows.

15.5 References

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16 Transition to a minimum chlorine usage in the drinking water production in the Netherlands

16.1 Introduction

Around 1910, direct surface water treatment commonly comprised of sedimentation and slow sand filtration (de Moel *et al.*, 2004). Slow sand filtration removes particles as well as pathogenic bacteria. In order to meet the growing water demand, rapid sand filtration was introduced prior to slow sand filtration to reduce the load of the slow sand filtration. Later, coagulation and flocculation were applied to reduce the load of the rapid sand filtration. The continuous increase of the water demand limited the application of slow sand filtration because slow sand filtration uses a lot of space. Therefore, slow sand filtration was more and more replaced by chemical disinfection (breakpoint chlorination). The first known application of chlorine in drinking water treatment is in Belgium in 1902 (AWWA, 1971). The emergence of ozone for disinfection usage was impaired around 1920 because of the increased availability of chlorine caused by the need for nerve gasses in World War I (Wijnstra, 1977; Lenntech website). Breakpoint chlorination was introduced in drinking water treatment in 1939 for ammonia removal purposes (White, 1972).

In many places in the world, chlorine is used in drinking water treatment and distribution systems. An advantage is that is a low cost disinfectant and it is easy to control. Chlorine can be applied for several purposes (Kruithof, 1984):

- Transport chlorination. Chlorine is added in order to prevent biological growth in pipes used for transport over large distances. Fouling of such pipes could lead to reduction of capacity and an increase of energy utilization.
- Breakpoint chlorination. Chlorine is added in order to remove ammonia and for disinfection purposes.
- Process chlorination. Chlorine is added in order to prevent biological growth in filtration steps in water treatment.
- Iron oxidation. In case iron salts are used for coagulation purposes in water treatment, iron (II) salts need to be oxidized to iron (III) salts by adding chlorine. Unlike the other applications, in this case chlorine is not added directly to the water.
- Post-chlorination. Chlorine is added to the treated water in order to maintain a disinfection residual throughout the distribution system. The disinfectant residual present in treated water entering the distribution system in many cases originates from water treatment, hence the presence of chlorine in the finished water has not always been based on a separate decision (van der Kooij *et al.*, 2002).

In the Netherlands, disinfection is not applied in the majority of groundwater treatment facilities since the soil passage effectively removes micro-organisms. By the end of the nineteenth century, approximately 50% of the drinking water was produced from surface water in The Netherlands. In 1939, this percentage had dropped to 25%, and the majority of the drinking water was produced from groundwater (50%) and dune water (25%). In the 1930's and 1940's, more water was extracted from the dunes than naturally replenished by rain, leading to salt intrusion (de Moel *et al.*, 2004). Therefore, in this period several surface water pretreatment facilities were built in order to infiltrate the pretreated water into the dunes. The water had to be transported for tens of kilometers (in some cases more than 60 kilometers) and transport chlorination was applied in order to prevent biological growth in the mains. In the 1970s chlorine used was common in the Netherlands for surface water treatment.

In 1974, it was discovered that disinfection byproducts such as trihalomethanes (THM) are formed during chlorination (Rook, 1974; Bellar and Lichtenberg, 1974). Some of these byproducts cause toxicological and mutagenic effects. In the Netherlands, discovery of THM led to a strong joint effort of the drinking water companies and KIWA (now KWR) to investigate the possibilities to reduce the formation of these harmful byproducts. Nowadays the application of chlorine in the Netherlands is limited to a minimum amount.

Important arguments for the use of a disinfectant residual are that the presence of a residual reduces the risk of microbial contamination that may occur in case of ingress of water, and the presence of a residual inhibits the growth of micro-organisms in the network. Some of the important drawbacks of chlorine usage are the formation of disinfection byproducts that may cause carcinogenic activity, taste and odor complaints and a negative opinion by customers. Also, chlorine is less effective as a disinfectant against some relevant microorganisms such as viruses and parasitic protozoa (Medema, 2009).

The advantages and disadvantages of disinfection with chlorine as well as the required conditions for production and distribution of drinking water without chlorine as a disinfectant have been reported by van der Kooij *et al.*, (1999); van der Kooij, (2002); Noij, (1989); Smeets, (2009) and Medema, (2009). Some of the important conditions that have to be met in order to distribute drinking water without disinfectant residual are usage of the best available source, a multi-barrier treatment, production of biostable water, good engineering practices to prevent water ingress, and strict procedures for hygiene during mains construction and repair. Although the technical approach to reduce chlorine usage has been disseminated, there are only a limited number of cases worldwide. Some other European countries such as Denmark, areas in other Nordic countries, areas of Germany, Luxembourg and Switzerland are known to produce drinking water without the usage of chlorine (Medema, 2009).

In this chapter, we analyse the characteristics of the transition from the situation in which chlorine was commonly applied to the situation in which chlorine is hardly applied in drinking water production in the Netherlands. We consider the production and distribution of bacteriologically safe drinking water as a social-technical system which is affected and steered by several actors and trends in the SEPTED-fields. The analysis include the identification of the main drivers and actors, as well as the pace of the changes. The research focusses on the development of chlorine applications rather than the effects of its reduction on water quality. By gaining insight into the transition in the chlorine usage in the Dutch drinking water sector, we attempt to reveal the drivers behind this specific transition. This provides insight in how transitions take place in the water sector.

16.2 Method

Social-technical systems are dynamically stable and are able to resist changes, (§ 1.3.1). The MLP described in (§ 1.3) is used to describe the transition towards a minimum usage of chlorine in the production of drinking water in the Netherlands. The production of drinking water takes place according to formal rules and norms, informal habits and principles and technical boundaries. All this leads to a stable unity which cannot be easily manipulated or adapted. In this research, the developments of the annual chlorine usage is described for the period of 1950 up to the present.

The transition of the chlorine usage in The Netherlands is analyzed according to the transition phases model described in Figure 6. Drivers and actors are identified. We characterize these drivers and actors according to the influence-levels as shown in Figure 6. These drivers might be applicable for future transitions and may be of use in drinking water infrastructure forecasting programs. Also, the classification according to the influence-level model provides insight into the degree of influence and dependency of water companies in relationship with certain drivers.

An extensive literature review was performed in order to obtain quantitative data on i) the annually used amount of chlorine and ii) the number of chlorine applications or the number of facilities at which chlorine was applied in The Netherlands. The literature review involved peer reviewed papers, professional magazine papers, manuals, course books, reports by RIVM, reports by KIWA (now KWR), water company annual reports (e.g. WRK) and websites. The research focused on the period between 1950 and 2013.

In The Netherlands, chlorine dioxide is used for post-disinfection purposes. Before, this process was known as post chlorination. In this research, no such distinctions were made for the different types of chlorine-based components. That is, each chlorine-type (e.g. chlorine, chlorine dioxide, hypochlorite, chloramine) application is considered equally and counts as a chlorine application.

In some cases, data concerning the annual chlorine usage (tons/year) and the number of chlorine applications were available in literature. For other cases it was not possible to attain exact data on the development of the annual usage of chlorine and the number of chlorine applications. In those cases an estimate was composed for the annual amount of chlorine based on the number of chlorine applications, an estimation of an average chlorine dosage (mg/L) and the production capacity of the facilities. Also, drinking water sector experts were interviewed and requested to make a best estimate based on expert judgment.

In September and October of 2013, interviews were conducted with several drinking water professionals having profound knowledge and expertise in relevant fields (drinking water treatment, microbiology). These interviews were conducted in order to obtain insight into the relevant socio-technical processes that occurred during the transition.

The production facilities included in the research are the drinking water facilities that use surface water and dune water, and the few groundwater cases that are reported by Kruithof (1984). The German facility ‘Roetgen’ is included in the research since chlorinated drinking water is supplied from this site to the south-eastern part of The Netherlands.

As indicated above, many aspects of the application of chlorine in the production and distribution of drinking water have been reported extensively. Meijers (1978), Kruithof (1986) and Noij (1989) reported about the annual usage of chlorine in the Dutch drinking water sector and the reduction thereof in the period of 1976 – 1984. In order to get an indication of the chlorine usage prior to 1974, the overview was extended, based on additional data and estimations. Additional data were obtained for one large facility for the period 1971 – 1976 (Kuyt *et al.*, 1985). An estimation for the annual chlorine usage for the period between 1950 – 1974 was based on the assumption that drinking water produced from surface water had a chlorine consumption of 13 mg/L. This assumed average total dosage is in agreement with reported typical average dosages of 2 mg/L for transport chlorination, 5 – 10 mg/L for breakpoint chlorination, 5 – 10 mg/L for iron oxidation and 0,2 – 2 mg/L for post chlorination (Kruithof, 1984). The specific value of 13 mg/L was used to enforce a match with the curve based on reported values for annual chlorine consumption in the early seventies.

This research presents an indication of the development of chlorine consumption, rather than focusing on exact data.

16.3 Analysing the transition

The results are presented in two sections. The first section describes the development of the annual chlorine usage (tons/year) and the number of chlorine applications in The Netherlands in a quantitative way. The second section presents insight into the sociotechnical processes that occurred during the transition in the usage of chlorine for water treatment in The Netherlands, hence the transition characterization, according to the theoretical approach described in § 3.1.

16.3.1 Quantitative results: data on chlorine usage, plant changes and operational adaptations

The annual chlorine usage was estimated for the Netherlands for the period from 1950 up to the present situation, (Figure 48). In addition to the annual chlorine usage expressed in ton/year, the number of chlorine applications is graphically presented in the figure as well, in order to make a comparison between the change of annual chlorine consumption and the number of chlorine applications. The development of the annual chlorine usage is analyzed with a reference to an specific application: chlorination in treatment and post-chlorination. Chlorination in treatment is analyzed by dividing the entire period (1950 – present) in three time frames.

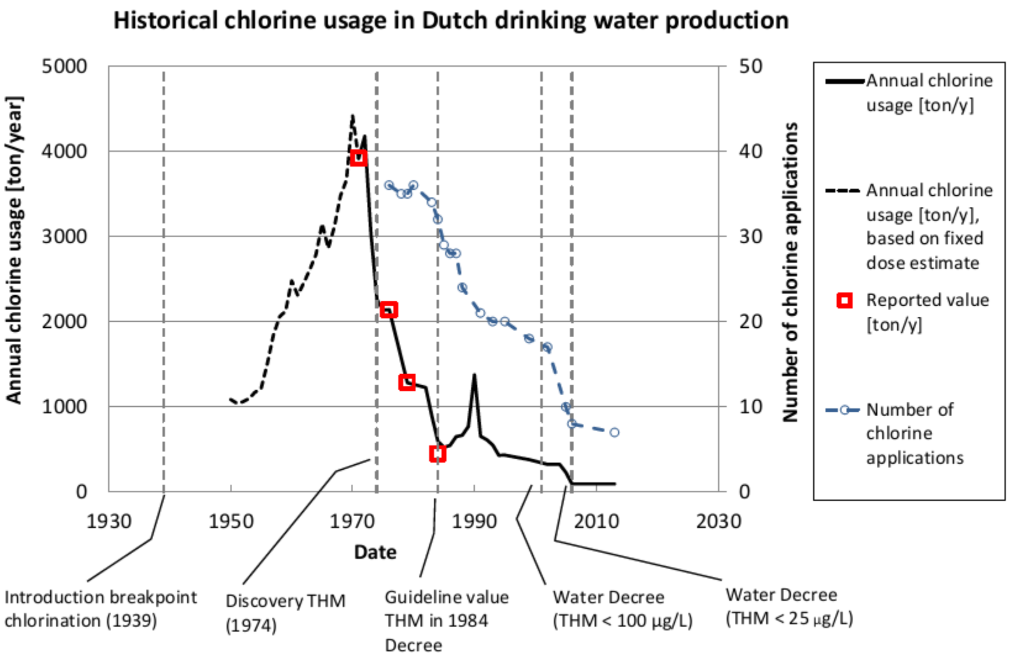

FIGURE 48 INDICATION OF THE HISTORICAL CHLORINE USAGE IN DUTCH DRINKING WATER PRODUCTION FOR THE PERIOD BETWEEN 1950 AND PRESENT. 'REPORTED VALUES' (MARKED ☐) ARE BASED ON DATA AVAILABLE FROM LITERATURE. 'ANNUAL CHLORINE USAGE' (SOLID LINE) IS A COMPOSED ESTIMATION BASED ON DIFFERENT SOURCES. 'ANNUAL CHLORINE USAGE, BASED ON FIXED DOSE ESTIMATE' (DOTTED LINE) IS AN ESTIMATION BASED ON THE ANNUAL USAGE OF SURFACE WATER FOR DRINKING WATER PRODUCTION AND A CHLORINE DOSAGE OF 13 MG/L FOR ALL SURFACE WATER TREATED. 'NUMBER OF CHLORINE APPLICATIONS' (DOTTED LINE WITH O-MARKERS) IS ON THE RIGHT AXES.

16.3.2 Chlorination in treatment

Period from 1950 – 1974

The estimated annual chlorine usage increases between 1950 – 1970 because of the increased use of surface water for drinking water production. This section of the curve is based on the annual surface water usage for drinking water production (CBS website) and an assumed total average chlorine dosage of 13 mg/L for all surface water treated.

As a consequence of this methodology, a sharp peak in annual chlorine consumption arises in 1971. It is not known whether the chlorine consumption actually peaks on the indicated moment. However, the peak has most likely occurred around this period. Although, there is not a reported value of the exact height of the peak, based on discussions with experts and literature Figure 48 represents a fairly accurate estimate.

The sharp decrease of the chlorine usage between 1971 – 1974, prior to the discovery of the disinfection byproducts, is ascribed to the changes occurring at one specific facility (Berenplaat, Water company Evides). During these years, this facility changed both its surface water source as well as the technology for iron oxidation (Kuyt *et al.*, 1985; PATO, 1985).

Mid 1970s – early 1980s

In the Netherlands, discovery of THM led to a strong joint effort of the drinking water companies and Kiwa (nowadays called KWR) to investigate the possibilities to reduce the formation of these harmful byproducts. That research comprised of investigating the following options (Kruithof, 1984):

- Dosing of chlorine was commonly applied and in many cases an excess dose was applied. It was investigated if the operation of the treatment could be optimized by determining i) the conditions under which dosing of chlorine was actually required and ii) what dosage was required.
- The byproduct formation mechanisms were investigated.
- It was investigated if precursors for byproduct formation could be removed.
- It was investigated in what way the byproducts could be removed once they were formed.
- The analysis and characterization of the byproducts as well as the determination of the acute and long-term health effects (both toxic and mutagenic) were investigated.
- Alternative technologies for disinfection and other purposes for chlorine addition were investigated.

Some of the recommendations based on this research were implemented quickly and successfully. This led to a decrease of the chlorine usage of 40% within three years (Kruithof, 1984) and consequently a decrease of byproduct formation. The number of chlorine applications was not yet reduced. This initial improvement was realized due to the following adaptations:

- adaptation of the chlorine dosing conditions in transport chlorination by defining temperature criteria. The chlorination was limited to the summer period, during which the dosage was reduced. Besides, chlorination was abandoned during the winter period.
- limiting breakpoint chlorine usage by closely monitoring the actual breakpoint curve.
- reduction of iron oxidizing chlorine usage.

1980s -Now

The research efforts regarding chlorine usage continued in the beginning of the 1980s, leading to a further reduction of the chlorination usage.

The water quality of the rivers Rhine and the Meuse regarding the ammonia concentration significantly improved during the seventies. These improvements as well as the selective intake of river water in the Biesbosch reservoirs (ammonia criterion) increased the possibilities for replacing chemical ammonia removal (breakpoint chlorination) with biological ammonia removal (PATO, 1985).

The following facility investments and optimizations have contributed to the overall chlorine reduction:

- further reduction of process chlorination and iron oxidation;
- introduction of biologically active filtration and biological ammonia removal (replacement of chlorination with sand filtration);
- replacement of chlorination with micro-sieve filtration or activated carbon filtration.

The chlorine usage shows an increase in the eighties because of the start-up of a newly built pretreatment facility (WRK III). The operation of this facility also causes the peak shown in 1990.

The final two facilities with breakpoint chlorination did not yet meet the 2001 Dutch standard regarding the parameter 'sum of trihalomethanes' (Versteegh, 2002; Versteegh, 2003), until the breakpoint chlorination was abandoned and replaced with advanced oxidation and UV disinfection processes in 2004 and 2005.

Some of the major facility changes (both investments and optimization) are listed in Table 22.

16.3.3 Post-chlorination

The post-chlorination was practically left unaffected in the initial effort in the 1970s for chlorine reduction. As off 1979, two facilities of Dunea applied incidental post chlorination. The efforts of the chlorine reduction in the water treatment led to lower concentrations of disinfection byproducts, but it was discovered that this positive effect was partly erased due to the strong amount of disinfection byproduct formation during distribution (Kruithof, 1980). Therefore, the research continued focusing on post-chlorination as well.

In 1983, the water company of Amsterdam stopped its post chlorination (Schellart, 1990). After an experiment in which the post chlorination was reduced in several steps, the water was permanently distributed without disinfectant residual. Later, some other drinking water companies stopped post-chlorination as well. Currently, a small number of facilities still use a small dose of chlorinedioxide, as polishing step in treatment.

16.3.4 Transition characterization

Socio-technical processes during the transition

Dutch drinking water companies have pursued a strong policy to minimize formation of unwanted chlorination byproducts ever since the reporting of the presence of such components. This policy was based on the findings of the joint research program of the Dutch drinking water companies conducted by Kiwa (now KWR). Before, chlorine was used in excess according to the philosophy 'it may not help, but it won't harm you either'. The new philosophy was based on the principle that disinfection needs to be a thoughtful balance between microbiological advantage and toxicological disadvantage (Schellart, 1990).

TABLE 22 SOME MAJOR PLANT CHANGES AND OPERATIONAL CHANGES CONCERNING CHLORINE APPLICATIONS IN THE NETHERLANDS. CURRENT NAMES OF DRINKING WATER COMPANIES ARE USED.

Date	Occurrence
< 1976	The significant reduction of chlorine usage in the early seventies, prior to the discovery of disinfection byproducts, is caused by the reduction of chlorine usage at the Berenplaat facility of Evides. This reduction was caused by a combination of the switch to a different water-source with lower ammonia concentrations, and an alternative technology for the oxidation of iron (II) (Kuyt *et al.*, 1985). The latter change was also motivated by safety issues of chlorine handling.
1980	The chlorine usage shows an increase in the eighties due to the start-up of the pretreatment facility WRK III in Enkhuizen in 1980 (transport chlorination).
1983	The post chlorination of both facilities of the Water company of Amsterdam (Weesperkarspel and Leiduin) is stopped.
1984	The transport chlorination at the pretreatment facility of Bergambacht (Dunea) was stopped.
1984	Chlorination usage for iron oxidation at Evides is nearly reduced to zero.
1986	The transport chlorination at the pretreatment facility WRK I/II was stopped in the mid-eighties because of the installation of rapid sand filtration.
1987 1991	The new facility of Braakman (Evides) starts up, initially with breakpoint chlorination. The breakpoint chlorination at Braakman was replaced with ozonation in 1991.
1988	Facilities Ouddorp (Evides) and De Punt (Watercompany Groningen) stop post chlorination.
1993	Dunea adapted the dune water intake (cover) in 1992 at the Katwijk facility.

1995	The transport chlorination at the pretreatment facility WRK III in Enkhuizen towards the dune area of PWN stopped in the mid-nineties due to the installation of activated carbon.
2002	The transport chlorination at the pretreatment facility of Brakel (Dunea) was replaced with micro-sieve filtration.
2004	Replacement of breakpoint chlorination with advanced oxidation process (UV/H_2O_2) at the Andijk facility of PWN.
2005	Evides considered replacement of breakpoint chlorination at the Berenplaat facility since 1989. Extensive research was performed first to the application of ozone and UV-disinfection. Breakpoint chlorination was replaced with UV disinfection in 2005.
2006	Dunea reintroduced post chlorination at the Scheveningen facility in 1995. They changed the dune intake process and covered the rapid sand filtration in 2005, after which they stopped post chlorination in 2006.

Engineers from most chlorine applying drinking water companies participated in various research steering committees. This research and the implementation of its recommendations was initiated by the Dutch drinking water sector first without obligations set by the Health Inspectorate. In the nineteen seventies, the Vewin (association of the Dutch drinking water companies) proposed guideline values of 0,55 mmol/L for THM and 70 µg/L for chloroform (Lekkerkerker-Teunissen, 2012). Within the first few years after proving the presence of harmful disinfection byproducts the Dutch drinking water sector was able to manage a 40% reduction of the chlorine usage. Later, the drinking water sector undertook the initiative to stay below 50 µg/L for chloroform. The first implementation of recommendations could occur relatively fast, hence drinking water company's decision makers agreed on implementation, because of a combination of convincing research results, a strong influence of both the steering research group and the Vewin, and the participation of members of the drinking water companies in the research groups. As the drinking water sector reacted vigorously and effectively, the initial involvement of the legislator might be qualified as cooperative and following rather than compulsory and steering.

The Drinking Water Decree of 1960 only contained eight standards. The revised Drinking Water Decree of 1984 contained up to sixty standards. This revision included a guideline value of 1 µg/L for hydrocarbons, but in practice higher THM values are allowed (van der Kooij, 2002). The standard for THM in the Drinking Water Decree of 2001 was based on a considered negligible excess cancer risk of 10^{-6} (life time exposure). In this revision, the standard for the sum of THM is 25 µg/L and a standard of 10 µg/L for individual THM components, in case chlorine is used for disinfection purposes. In other occasions, the standard of 1 µg/L holds. In the revision of 2001, a transitional phase of five years is included during which the standard for the total amount of THM is 100 µg/L (until 2006). These standards have remained unchanged in the latest Drinking Water Decree of 2011.

Drivers for the transition

Complaints about taste and odor due to the application of chlorine have been recurrent over time. Between 1940 – 1960 this subject attracted much attention resulting in research and the application of different types of chlorine containing disinfectants (van der Kooij, 2002).

Based on the literature, interviews and the combination of historical events and the development of chlorine consumption shown in Figure 9, it can be concluded that the discovery of harmful byproducts of chlorination is the initiator and the most important driver for the transition towards a minimum chlorine usage. The discovery changed the mindset from dosing chlorine in excess towards dosing based on the balance between microbiological advantage and toxicological disadvantage. The analysis showed that chlorine would not have been reduced as fast and as far if the harmful byproducts would have stayed undiscovered. Therefore, human health appears to be the main driver behind the transition.

The research and activities contributing to the reduction of the amount of byproducts in drinking water were initialized by the drinking water sector, i.e. the drinking water companies, Kiwa (now KWR) and Vewin. The initiatives (both the reducing activities as well as the research) started within a few years after the detection of byproducts, prior to the definition of byproduct standards. Hence, there was a strong will and sense of responsibility (a strong 'drive') of the drinking water companies for action and change. This willingness showed to be really strong, since it did not only lead to the reduction and ultimately the abandoning of chlorine in water treatment, but nearly in an abandonment of chlorine in distributed water as well. The research was conducted in a joint program and measures were taken collectively, probably because all the water companies faced the same risks.

Within the period of concern, the Drinking Water Decree was revised twice. Legal standards and guideline values on byproducts were formulated, and therefore contributed as a driver for further reduction of the chlorine consumption. The standards might have had the largest influence in several replacements of breakpoint chlorination and the application of alternative kinds of (chlorine based) post disinfection chemicals.

Due to the introduction of additional technologies, the multi barrier concept steadily grew (Smeets et al., 2009). The additional technologies, such as activated carbon, often were introduced for reasons other than disinfection, mostly because of organic micro-pollutant removal. In other cases, the chlorine application was replaced with an alternative technology. Some of these technologies were proven and already applied in the Dutch or foreign water sector. Further research and development of technologies such as membrane filtration, UV-disinfection and advanced oxidation processes provided new and solid solutions for replacing chlorine applications. Hence, a driver is the improvement, availability and feasibility of alternative technologies. Vice versa, as mentioned in the background, the discovery of the disinfection byproducts boosted the search of such alternative technologies. Certain types of chlorine products, e.g. liquefied chlorine gas, requires great care upon handling because of its hazardous properties. Also, chlorine production requires significant amounts of energy and the production process may be polluting. Safety issues of chlorine production and handling as well as the pollution occurring in the production process of chlorine can be considered to be (small) drivers.

The abovementioned drivers can be classified according to the level of influence model, § 1.3.2, as shown in Figure 49. Most of the drivers are in the transactional environment. The external pressure caused by the health risks of the external environment were addressed and solved by using the area of influence to generate new knowledge. This new knowledge, new technological options and the strong will and sense of responsibility of the drinking water companies led to a transition. Policy makers are key actors linking the transactional environment and the external systems. Legal standards, which are in the external system, can be indirectly influenced by involving policy makers in the process.

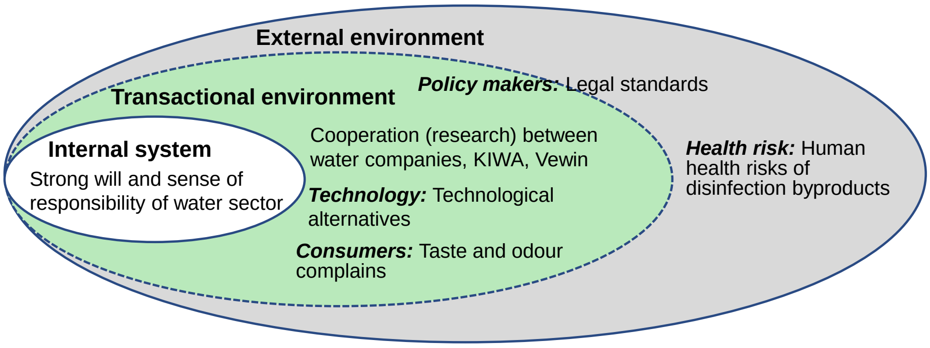

Figure 49 Classification of the drivers of the transition of chlorine usage in drinking water production in The Netherlands according to the three levels of influence model of Gharajedaghi.

Referring to the general analysis of transitions, the chlorine reduction can be characterized as follows:

- The overall transition from the time during which chlorine was commonly applied in excess in Dutch drinking water treatment to the phase in which chlorine usage is minimized took about three decades (1976 – 2005).
- The speed of change, concerning annual chlorine usage, takes off fast in the initial phase (fast penetration), and slows down towards the end. The change can be well described mathematically by the use of an exponential function.
- The speed of change, concerning the number of chlorine applications, shows the opposite pattern (slow penetration). Initially, the number of chlorine applications hardly changed, since it needs time to perform research of and invest in alternative technologies.
- The combination of a fast change of annual usage and slow change of the number of applications in the beginning is in accordance with the effort undertaken initially, i.e. optimization of operation (fast penetration).
- The size of change (the extent of adoption) is almost 100%, that is chlorine fully abandoned in drinking water treatment, and is only applied in a few cases for post chlorination.

Dynamics in the transition towards chlorine free distribution of drinking water

The transition started within a few years after the discovery of disinfection byproducts, the occurrence of the main driver. The initial take-off is fast and takes a couple of years. Within this first period, a quick and effective change is made through optimization of the operation of the existing facilities. This leads to a fast reduction of the annual chlorine consumption.

Later, the change of annual chlorine consumption slows down since investments are required to replace chlorine applications. Therefore, the change of the number of chlorine applications shows a rather slow take-off, and accelerates in the second halve of the period. The overall transition took about three decades.

The following factors determine the difference between the relative quick change of the annual chlorine consumption due to operational optimization of existing facilities, and the lag shown in the change of the number of chlorine applications due to investments:

- The adaptation of treatment processes is carefully planned. Most often, the actual revamping and construction of the facility is preceded with a phase of extensive research and conceptual design studies.
- Moreover, the investment in the treatment plant needs to match with the long-term investment agenda of the drinking water company. The timing of investments might depend on the actual age and the remaining expected technical and economic life span of the plant, even more so in cases where the water quality complies with the legal standards.
- In addition to the investment agenda and the technical and economic life span of a facility, also the available options such as source water quality and alternative technologies are important for the actual timing of investments.
- The aim was not to replace chlorine dosing technology, but rather the reduction of disinfection byproduct formation, which already had been accomplished for a great deal by optimization of existing processes. Some facilities did invest in the removal of disinfection byproducts, which would not lead to the reduction of chlorine usage.
- Finally, it is plausible that the company culture and the influence of important individuals could play a role in the decision of a company regarding when to adapt. Early adaptors will take action before new regulations are enacted. While laggards will adapt according a time schedule that legal regulations and other constraints define are requirements will met ‘just-in-time’.

16.4 Conclusion

This chapter describes the transition of the situation in which chlorine is commonly applied for drinking water production to the situation in which chlorine consumption is minimized in The Netherlands. This transition was initiated by health risk concerns and accelerated by the willingness of the drinking water sector to proactively act to minimize the risks. Drinking water companies showed a clear steering role by investing in research and innovation and by using their sphere of influence to update guidelines. This transition took three decades to reach almost 100% chlorine free water production. In this transition, the water companies have work together to steer and accelerate the transition. This transition shows a bottom up transition initiated within the drinking water regime and after that affecting the landscape.

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17 Transition in selection of raw water source

17.1 Theoretical framework

We see the abstraction of groundwater as a social-technical system that is influenced and directed by different actors and trends in the SEPTED fields.

Social-technical systems are dynamically stable and resist changes. There are formal rules and norms, informal customs and convictions, and technical constraints within which drinking water abstraction takes place. This forms a stable whole, which is not easily adapted or changed, see § 1.3.

17.2 Method

We have based our research on the phases shown in Figure 6. Our subject is the transition from a pure groundwater water company to a water company that uses both groundwater and surface water for its sources of raw water. In the course of our work, we have drawn on a number of different reports and policy documents, and also conducted three separate interviews with: 1) Sef Philips and Sandra Verheijden (Brabant Water, the then WOB), 2) Peter van Diepenbeek (WML), and 3) Jan Leunk (Province of North-Brabant).

The first step involves a description of the transition process for the two water companies. We describe the following phases (for each water company):

1 Predevelopment
2 Take off
    1 Getting the transition underway (between predevelopment and take off): the transition's triggers.
    2 The start of the transition at the two water companies themselves.
3 Acceleration
4 Stabilisation (WML: stabilisation, WOB: backlash)

In the description of the process the differences between the two companies come to light. It is important for this research to determine how the water companies themselves have, or could have, exerted influence on the process. This is discussed in § 17.3.6.

17.3 Describing the transition

17.3.1 Predevelopment: groundwater as the source

In the Netherlands approximately two-thirds of the drinking water is produced from groundwater and a third from surface water. Traditionally, there has been a division between pure groundwater water companies, which only use groundwater to produce their drinking water, and drinking water companies that (also) use surface water sources. Both WOB (now Brabant Water) and WML, prior to the transition period, used exclusively groundwater for the production of drinking water.

17.3.2 Factors triggering the transition

There were a number of macro-level triggers that got the transition underway:
1 Starting in the 1970s, a strong growth in water demand was expected.
2 On 1 December 1970, the Pollution of Surface Waters Act came into effect.

3 The 1970s oil crisis.
4 European research into groundwater availability and its repercussion on national policy.
5 Increasing concern for nature and the environment in the 1980s.

Point 1 meant an (expected) increase in water consumption, while points 4 and 5 established limits to the volumes of groundwater available to satisfy the increased demand. At the same time, points 2 and 3 brought about a turnaround in water consumption, and water-saving became current.

In addition, there was pressure from within the sector itself:

1 Abstraction from several small, shallow abstraction points that were difficult to protect (especially in Limburg) needed to be addressed.

For WML the demand from the province to reduce the impact of groundwater abstraction on nature conservation was the most important stimulant to initiating research into the use of surface water as a drinking water source. An increase in water demand and the water quality at several phreatic abstraction points also played a role.

For WOB the expected increase in water demand was the most important stimulant for searching for an alternative for groundwater sources, combined with an end to the expansion of the abstraction at the Centrale Slenk groundwater system, related to point 4 and 5).

Water demand

In 1978, Vewin brought out a ten-year plan which contained a forecast for water demand for the 1978-1990 period, Figure 50. It anticipated that water consumption in the Netherlands would increase from 1 billion to 1.58 billion m^3 per year.

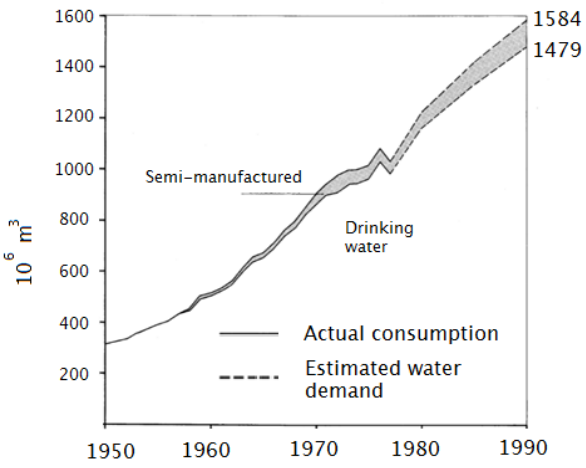

FIGURE 50 WATER CONSUMPTION 1950 – 1977 AND ESTIMATED REQUIREMENTS UNTIL 1990 (SOURCE: VEWIN TIENJARENPLAN '78).

The forecast increase was, among other things, based on the forecast growth in population from 13.6 million in 1974 to 15.2 million in 1990, and the forecast increase in household water consumption, from 113 litres per person per day in 1974 to 153 litres per person per day in 1990 (*Vewin, 1978*).

For WOB, an overall increase in water consumption of 33 million m^3 per year was forecasted: from $42x10^6$ m^3 in 1974 to $75x10^6$ m^3 in 1990. For WML, an overall increase in water consumption of 14 million m^3 per year was forecasted: from $40x10^6$ m^3 in 1974 to $54x10^6$ m^3 in 1990.

In actual fact, in 1990, the Netherlands population amounted to 14.9 million people (source: www.cbs.nl). Water consumption in 1992 had indeed increased, but only to 135 litres per person per day, thus below the forecast levels (Waterleidingstatistiek, 2000). During the course of the 1990s, there was even a decline in household water consumption. Figure 51 shows that actual drinking water consumption fell far short of the 1978 prognosis.

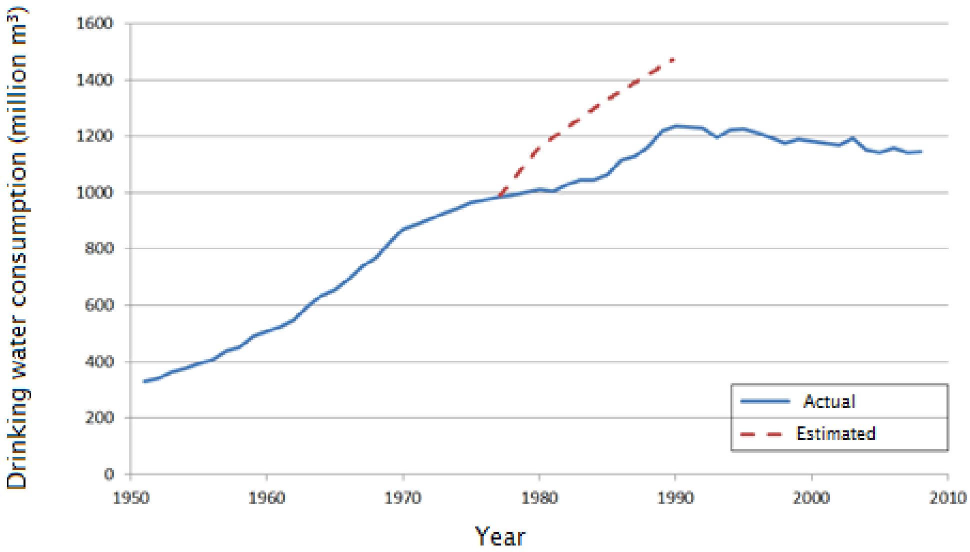

FIGURE 51 ACTUAL DRINKING WATER CONSUMPTION COMPARED TO 1978 FORECAST.

Pollution of Surface Waters Act

On 1 December 1970 the Pollution of Surface Waters Act (Wvo) came into effect, with the objective of countering and preventing the pollution of surface waters. The law prohibited the discharge of wastewater without a licence, or introducing harmful substances into surface waters in the Netherlands. The Wvo laid down the requirements that had to be met for the discharge of wastewater. Any wastewater that did not meet these requirements had to be treated.

For industry, the Wvo meant that the discharge of water became a cost item – both for its discharge and its treatment. As a result, the Wvo provided an impulse to water-saving in industry. Not for the sake of water-saving as such, but primarily because lower water consumption (and more water reuse) in industrial processes meant less wastewater.

The 1970s oil crisis (1973 and 1979)

The oil crisis, like the Wvo, had an indirect impact on water consumption. The crisis led to higher energy prices. Household amenities and appliances, such as showers, washing machines and dish washers, use water, but it was rather the energy required to heat the water that became a cost item. A comparable impact took place in industry, where various processes involve the heating or cooling of water, so that savings in water consumption also meant savings in energy consumption, see Chapter 14.

Groundwater availability

In 1977, the European Economic Commission decided to have a survey conducted into the available volumes of groundwater, in order to evaluate the degree to which these would suffice to meet future needs, Table 23 (Jelgersma, *et al*, 1982).

Up until the Second World War (WWII), water supply in the Netherlands hardly presented any problems. This changed in the period following the WWII because of the increase in population, strong economic growth and rising prosperity. Pollution of the rivers made the direct intake of water for drinking water problematic. Also, there was a deterioration in the quality of dune water, which increasingly consisted of infiltrated river water, and natural recharge of river water caused a decrease in the quality of groundwater. Furthermore, the abstraction of groundwater climbed to the point where natural vegetation were adversely affected by dropping groundwater levels. With this backdrop, a decision was made to evaluate the amount of groundwater that was available for abstraction.

TABLE 23 ABSTRACTION AND AVAILABILITY OF GROUNDWATER IN THE NETHERLAND BASED ON 1976 FIGURES (SOURCE: JELGERSMA, *ET AL* (1982))

		Abstraction in 10^6 m^3				Total available	Available for extension
Province	District	Public water supply	Industry	Agric ulture	Total	(in 10^6 m^3)	(in 10^6 m^3)
North-Brabant	North-West Brabant	-	-	-	-	-	-
	Land of Altena	6	3	-	9	15	6
	South-west Brabant	75	25	3	103	150	47
	Central North-Brabant	99	61	25	185	240	55
	North-east Brabant	7	15	6	28	34	6
Limburg	North Limburg	17	8	11	36	55	19
	Central Limburg	19	11	2	32	55	23
	South Limburg	30	28	-	58	85	27

Jelgersma, *et al* (1982) calculated the annual precipitation surplus to be 7,500 10^6 m^3. They also showed that the annual precipitation surplus does not represent the amount of abstractable groundwater water because:

- In a significant part of the Netherlands the abstraction of fresh groundwater is not possible because of the presence of shallow brackish groundwater.
- The water balance can, over long periods, show a much lower precipitation surplus.
- Eighty percent of the annual precipitation surplus occurs in the winter months. Since groundwater levels are already high at that time of the year, the possibility of storage is reduced and a lot of water is discharged as run-off.
- Dropping groundwater levels during the growing season have adverse effects on agriculture and nature.

The permissible abstraction volume in the Netherlands is set at about 1,900x10^6 m^3 per year. This volume is not spread evenly over the country; each region has its own estimate.

The abstractable volume finds its way into the Dutch groundwater and drinking water policy. It is incorporated into the Second National Drinking and Industry Water Structure Plan, which guides the provincial water planning.

The groundwater plan (1987) of the Province of North-Brabant indicates that there is a need for a more detailed evaluation of the abstractable volumes but, for the time being, the general national figures have to be used. This groundwater plan set the groundwater requirements of various areas in North-Brabant against the abstractable volumes, as presented in Table 24. The table shows that in central and eastern North-Brabant demand already exceeded supply, while a further increase in demand was forecasted. The groundwater plan (1987) therefore considered it necessary, in the short term, to research alternatives to groundwater abstraction.

TABLE 24 DEMAND FOR GROUNDWATER IN A 50% DROUGHT YEAR IN THE MID-1980S VERSUS THE SUPPLY OF GROUNDWATER (IN MILLION M^3/YEAR) (SOURCE: GRONDWATERPLAN 1987)

Areas	Current demand				Total	Supply
	Permanent abstractors		Non-permanent			
	Water companies	Industry	Agriculture	Drainage		
Central + eastern North-Brabant	170.7	51	46	46	313.7	285
Centrale Slenk	159.0	41.4	31	33	264.4	251
Peelhorst	11.7	9.6	15	13	49.3	34
Western North-Brabant	89.9	15.7	13	6	124.6	145
Total	260.6	66.7	59	52	438.3	430

National policy

In the Second National Drinking and Industry Water Structure Plan of 1985, the alternative water supply options Heel-Panheel (WML) and the Maaskant infiltration (WOB) were specifically referred to by name. The planning actions indicated the need for closer study and more detail for inclusion in the regional plan.

Increasing concern for nature and the environment in the 1980s

The late 1960s and early 1970s witnessed a growing concern about environmental pollution and the level of environmental awareness increased. In 1967, the original Nature Conservation Act was passed. In 1972 *Limits to Growth* was published. This book strongly influenced national legislation designed to preserve nature and prevent pollution. Resource consumption and depletion also became an issue – for example, with reference to fossil fuels, but also to water.

Jelgersma, *et al* (1982) pointed to the adverse effects of the dropping groundwater levels – a consequence of groundwater abstraction – on natural vegetation.

The groundwater plan also focused on the consequences of groundwater abstraction. It indicated that there was less groundwater available for agricultural crops, and semi-natural and natural vegetation, leading to harvest losses and changes, or the impoverishment of species composition in semi-natural and natural vegetation.

Small and difficult-to-protect abstraction points

By the late 1980s, WML had a number of small, shallow abstraction points that presented protection and water quality problems. These were the result of poor protection of the abstraction points in the past. In addition, the points concerned were shallow (phreatic) and located in an acidic environment where agricultural activities were an influence.

- Helden: nickel problem,
- Oostrum: nickel problem,
- Reuver: nitrate problem,
- Herten: planning: well field located in the city (Roemond),
- Californie: planning: province wants to extend greenhouse horticulture (it is still open, but the abstraction facility will be closed in the short term, December 2014).

The solution of the water quality problems called for relatively large investments at each of these abstraction points. Surface water abstraction also requires relatively extensive water treatment, but a treatment system is only needed at one location, so that the replacement of the small phreatic abstraction points involves economies of scale.

17.3.3 Start of the transition

The combination of growing demand and diminishing possibilities of expanding groundwater abstraction forced the provinces of North-Brabant and Limburg, and the WOB and WML water supply companies, to look for alternatives.

WOB

In 1990, in a commission from the Province of North-Brabant, a research project was conducted on the possible alternatives to groundwater abstraction in East-Brabant (Maas, 1990). The following alternatives were studied:
- Artificial recharge of surface water:
  - a Artificial recharge of Meuse water at Lith
  - b Artificial recharge of stream water at Groote Heide
  - c Deep recharge of canal water at Groote Heide
- Abstraction of river-bank filtrate:
  - a Meuse banks upstream from Samsbeek
  - b Sand extraction at Beers
- Abstraction of surface water
  - a Biesbos reservoirs
  - b Panheel reservoir

The researchers then studied, compared and scored the alternatives on a number of their economic and environmental characteristics. The report did not reach any conclusion as to which alternative was the best.

To meet the forecast demand for water, an extra of 20 million m^3/year was needed. Around 1989 it was decided (land-use implementation document) that WOB would receive a license for 10 million m^3 groundwater, with a trial period. At the same time, WOB would start a surface water project. Following the realisation of the surface water project, the licence for 10 million m^3 groundwater, with a trial period, would be surrendered in exchange for a surface water license.

Within WOB the following alternatives were considered:

- Maaskant Filtration Project (PIM) came the closest to groundwater, because it involved soil passage. PIM was planned for the banks of the Meuse, but the Waal River also flowed close by at the location so that there was an extra surface water backup.
- The transport of treated surface water from the Biesbos was dropped because it was relatively costly (pipe laying, but primarily the pumping of the water), and because WOB preferred not to use any surface water (groundwater was felt to be better and it was not known if the mixing of different water types could create problems).
- Deep recharge was considered a technique that was too new and unproven. Furthermore, the site for deep recharge (source: Maas, 1990) was located in the area of the Eindhoven Water company, NRE. But a decision was taken to run a test: DIZON, the Dutch acronym for deep recharge south-east Netherlands.
- Transport of drinking water from Limburg or Gelderland.
  WOB held discussions with WML. The Heel project consisted of various phases, and only in the second phase would there be surplus water available to be supplied to WOB. Since the water would not be available on time, Heel was dropped. In addition, the problems discussed for the Biesbos water option were also present in this case. Discussions were also held with the water company Gelderland. There were plans for the extension of water production at station Fikkersdries (Overbetuwe plan) but these were still under development, so this was not a possible alternative for WOB.

Therefore, WOB decided to proceed with PIM.

WML

In the first instance, WML was pressured by the Province of Limburg to develop surface water abstraction. This initiative was supposed to make a significant contribution to the province's policy directed at nature conservation. In the early 1980s, the Province of Limburg had studied, together with the drinking water agency RID, the potential of making use of quarry ponds for drinking water abstraction. As far as is known, no comparative assessment was made of the different abstraction alternatives.

Around the early 1990s, WML (director Vliegen), under pressure from the province, decided to start preliminary work on surface water abstraction in Central-Limburg. Even though it became clear in the mid-1990s that water consumption would increase less than originally forecasted, WML (director Huberts) decided to go ahead with surface water abstraction. Internal drivers, such as scale benefits – and thus cost-efficiency – flexibility and a quest for innovation, led WML to adapt and implement surface water abstraction.

17.3.4 Acceleration phase

WOB

In the first half of the 1990s, an Environmental Impact Assessment (EIA) was carried out for the PIM project. The objective was to produce 25 million m^3 of drinking water with PIM in 2000. Depending on the increase in water consumption, the project could achieve an ultimate capacity of 50 million m^3. Nature development was cited as an important secondary objective.

The PIM plan would consist of: an intake basin, pre-treatment, an infiltration system, soil passage, with recovery via enclosed abstraction techniques (drains/wells), and post-treatment.

Table 25 presents an overview of the key actions and licences required for the realisation of PIM; an indication is also given of the status of each action. These actions began in 1990 and the total process took approximately a decade.

TABLE 25 REQUIRED LICENCES AND ACTIONS

Licence / action	Status
Preparatory actions	
Organise Environmental Impact Assessment Report	EIA is complete.
Communication with the community	Information evenings were begun during the EIA process. Afterwards, a sounding-board committee with the community was formed. Information evenings were also held around important licence applications (e.g., abstraction licences for the drainage for the treatment buildings).
Purchase of land required and buying-out farmers.	Complete: all land required has been acquired.
Conduct of tests	Two tests were conducted. One after infiltration and nature development, begun shortly after 1992. Later, another test infiltration trench was built. These tests provided insight into the possible infiltration capacity, quality changes of the water in the soil, ways of keeping the bottom of the trenches clean, and into the opportunities for nature development. The test infiltration trench was built to study whether it was possible to build an infiltration trench “in the wet”. The background to this was the sensitivity regarding the settlement damage to the buildings/zone surrounding the intended infiltration area.
Licences	
River Act licence for raising embankment	Was granted but, later, in the context of the “Room for the River” programme, was revoked.
Other licences: well-point system for pipelines, buildings, building licence, development plan, environmental licenses, archaeology, earth removal licences (for basin and infiltration trenches).	All these licences were granted. Appeals to the Council of State regarding the development plan and others were dismissed; thus licences are definitive
Installation/building main components	
Intake basin	Necessary licences granted, basin is built.
Installation/construction of other main components (Waal water intake point, Waal-Maas transport pipeline, pre- and post-treatment, infiltration and recovery, transport).	Definitive designs and specifications done, but not implemented.

WML

The preparatory work for the realisation of the surface water abstraction at Heel began in the first half of the 1990s. Approximately six years were assigned to the preparations, which included, for example, selecting a system, organising an EIA (Environmental Impact Assessment) and applying for the licences.

The travel time for a number of the wells was short (approximately 30 days). This is less than the 60 days that has always been considered the minimum for drinking water purposes. Specifically for Heel, research was done into the removal of microbes (phages) in the case of shorter travel times. The results showed that, for the conditions in Heel, 30 days was sufficient time for a 10^4 reduction of *Cryptosporidium*, *Giardia*, viruses and phages.

The Heel project involved about 175 different licences, including production licences, abstraction licence, discharge licence, environmental licence, Nuisance Act, etc. In the process of arranging and applying for licences, great attention was paid to collaborating with the licensing authorities and receiving their input. For instance, in organising the zone in an open manner, the abstraction activities could be combined with recreational ones. Partly thanks to good preparatory work, and the fact that the authorities were closely involved in the project's development, not a single licensing procedure underwent any delay.

In 1998, the construction of the treatment system and the installation of the wells got under way; it was completed in 2001-2002.

17.3.5 Stabilisation phase

The stabilisation phase occurs after the acceleration phase. At this point the two projects of Brabant Water and WML diverge. At WML the entire transition has been gone through, and a new stable situation has been created, in which the company is using both groundwater and surface water as its sources. Brabant Water, in turn, is experiencing a so-called backlash: the transition has not been pushed through and the company still uses only groundwater as its drinking water source.

PIM: backlash

In the early 1990s water consumption was evidently levelling off. The EIA itself had examined the possibility that the water consumption prognoses might have to be readjusted as a result of water-saving measures. But, at that time, it was assumed that even in the most favourable scenario the maximum allowable licence amount of 98.7 million m^3 would not be sufficient over time, see Figure 52.

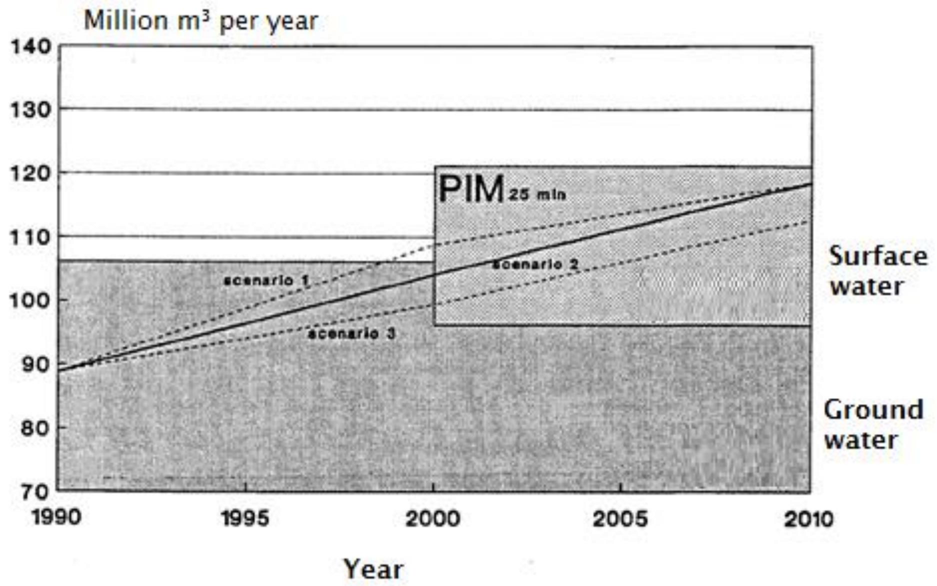

FIGURE 52 PROGNOSIS OF DRINKING WATER CONSUMPTION AND MAXIMUM LICENSE CAPACITY (SOURCE: MER, REPORT PART 1).

PIM had built-in phasing, whereby an initial project would be implemented for the abstraction of 25 million m^3 per year. In the course of the 1990s, because of the further reduction in the water consumption forecasts, the phasing was adjusted so that the first phase would involve the abstraction of 12.5 million m^3 per year.

In the second half of the 1990s, the license previously granted within the framework of the River Act was revoked. This meant that an intake basin could not be used. The intake basin was an inextricable part of the plan. It allowed for the temporary suspension of the intake from the Meuse, while there was still sufficient supply, and it would help ensure a more even water quality. Moreover, part of the intake basin would function as an analysis basin to allow for close monitoring. Without the intake basin, the subsequent steps had to be re-examined, particularly the pre-treatment.

The complete adaptation of the project to a PIM without an intake basin constituted a big adjustment, involving new research and investment. Visscher, the director at the time, who was at the end of his term, decided to postpone the decision as to whether or not to proceed with PIM. The backdrop to this decision included the political situation, the still relatively newly-adjusted consumption forecasts and Visscher's upcoming departure as the director of WOB.

The new Director Jellema at first followed the same course. While the definitive decision was postponed, it became increasingly clear that drinking water consumption was stabilising and even declining, as can be seen in Figure 53. By 2000, water consumption had already been slightly declining for a period of 10 years. This applied not only to WOB's supply area, but to the Netherlands as a whole. Moreover, the method of forecasting water consumption was further refined, so that the calculations became more reliable. For Brabant Water, the stabilisation and later decline in water demand also had to do with the introduction of the groundwater tax, which led many farmers to abstract their own water rather than buy it from the water company.

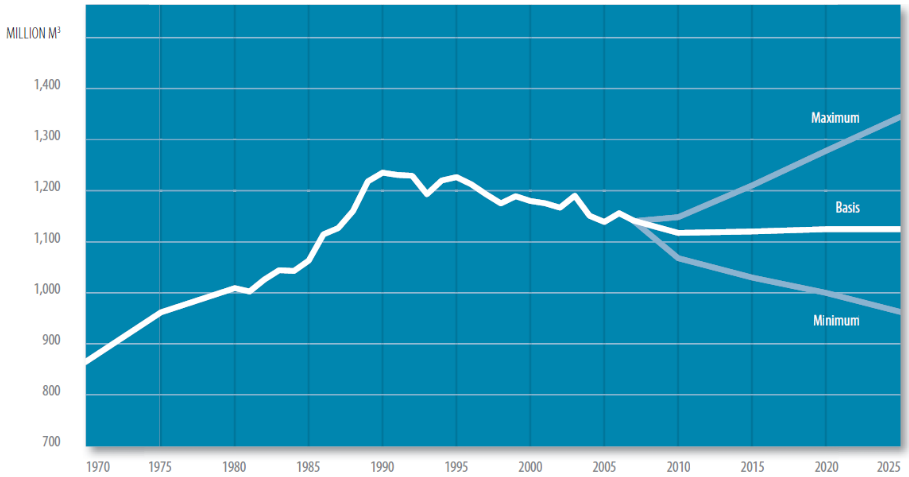

FIGURE 53 HISTORY AND PROGNOSIS OF DRINKING WATER DEMAND 1970 – 2025 (SOURCE: VEWIN DRINKING WATER STATISTICS 2008).

In 2001, WOB had 29 abstraction points, with a total licence capacity of 150 million m^3 per year. Of this, 11 million m^3 licence capacity per year was granted for a trial period. At the time, WOB had a pending application for the conversion of its temporary licences for 9 million m^3 into definitive ones. Vewin's *Waterleidingstatistiek* of 2001 shows that WOB produced 104 million m^3 of drinking water that year, so that its existing groundwater licences were sufficient to meet demand. Since there was enough room within the existing licences, WOB began by designing a modular PIM and, at a later stage, effectively put the project on ice.

In the 2000-2001 period, WOB set up the "Brede Kijk" (broad vision) project with the aim of getting a complete picture, on the one hand, of water needs and, on the other, of the abstraction levels required. Upon the satisfactory completion of the Brede Kijk project, a decision was taken to drop PIM. Sustainability played a key part in the Brede Kijk project. Together with the province and a number of societal partners, WOB scored each of its abstraction points on three sustainability themes:

1 Impact of the abstraction point on the surroundings,
2 Impact of the surroundings on the abstraction point and
3 Costs and environmental aspects.

After the scoring, the province decided on the licenses. Of the 10 million m^3/year for which in 2001 trial-period licences were granted, 6 million m^3/year received definitive licences. At the Lieshout point, of the 4 million m^3 capacity, 2 million m^3 was granted definitive licences and 2 million m^3 was not. And the trial-period licences granted for 2 million m^3 at Helvoirt were not made definitive. Apart from the 4 million trial period capacity that was not granted definitive licences, the licences for another 6 million m^3 were revoked, namely:

- Budel: 2 million m3/year
- Vessem: 2 million m3/year
- Empel: 2 million m3/year.

Following the Brede Kijk project, a number of other reallocations were carried out with a view to further optimising water supply. These reallocations concerned the quality, costs and sustainability adaptations of the abstraction points.

Heel: transition to the use of surface water as source

The abstraction at Heel has a licence for 20 million m^3 per year. Current production is approximately 15 million m^3 per year. The site is situated on a collection pipeline with a number of groundwater pumping stations and booster pumping installations. For each pumping station, a minimum and maximum mixing ratio of water from Heel and the locally produced water is defined. The quantity of water produced by Heel or by groundwater abstraction points can be increased or decreased within these ratios/boundaries.

The operational management is directed at cost-efficiency and the supply of good water of stable quality. The cost-efficiency is partly a function of the tax regime and of sales. Because of the abolition of the groundwater tax and the associated elimination of the infiltration deduction, the production of drinking water from groundwater again became cheaper than the production from surface water. In the past, an infiltration deduction applied to the abstraction at Heel, so the water produced there was cheaper than is presently the case. This is the reason why, within the framework of the earlier defined mixing ratios, there is a little more abstraction of groundwater and a little less of surface water.

One of the most important drivers was the conflict between groundwater abstraction and nature conservation in Limburg. As a result of the installation at Heel, a number of phreatic abstraction points were closed. It is not clear whether these points were those that most contributed to the conflicts with nature conservation. Indeed, the province still faces the problems. WML is also affected: for example compensatory measures have been taken in Heel and in Bergen.

The WML raw water matrix indicates the preference for the different sources. Although surface water is not in top position, WML realises that Limburg needs surface water because there is not enough deep groundwater (the preferred raw water) available.

Heel was designed assuming a maximum intake stoppage period of 2 continuous weeks following the appearance of quality problems. Now that Heel has been operational for 10 years, it turns out that both the number of intake stoppages as well as their maximum duration have been much larger than anticipated.

- Two lengthy intake stoppages occurred as a result of bad water quality. In neither case was it immediately clear what the cause of the bad water quality was. It took a long time to track down the source. To avoid these problems in the future, agreements were reached with the Dutch Directorate for Public Works and Water Management (Rijkswaterstaat), the water boards and the Flemish Environment Agency (VMM). The instant that WML has to stop the intake because of an accidental discharge detected at WPH, but which is not detected in Eijsden, water quality samples are to be taken immediately. The sampling points are pre-established at several discharge points and inflow of streams in the Meuse, upstream from the intake station. It is hoped that in this manner the source of the pollution can be traced more quickly.
- The intake is intensively monitored: chemically, physically and biologically. Thanks to the continuous biological monitoring, the intake is regularly suspended in a timely manner to prevent the intake of contaminated Meuse water. However, one cannot always trace the possible reason for the biomonitor’s reaction.
- The fact that intake stops have occurred more frequently than anticipated is connected to the intensification of surface water monitoring, significant advances in analytical techniques – which means more substances can be analysed at lower detection limits – and changes in the Meuse’s discharge pattern. Since 2000, the summers have become clearly hotter and drier, and drought periods last longer (2003, 2011). Drought periods result in a lower river discharge, which means that any possible pollution is less diluted. Also, Heel is located relatively close to discharge points in the Luik district and the Chemelot industrial complex. Water companies located further downstream have far less water quality problems.

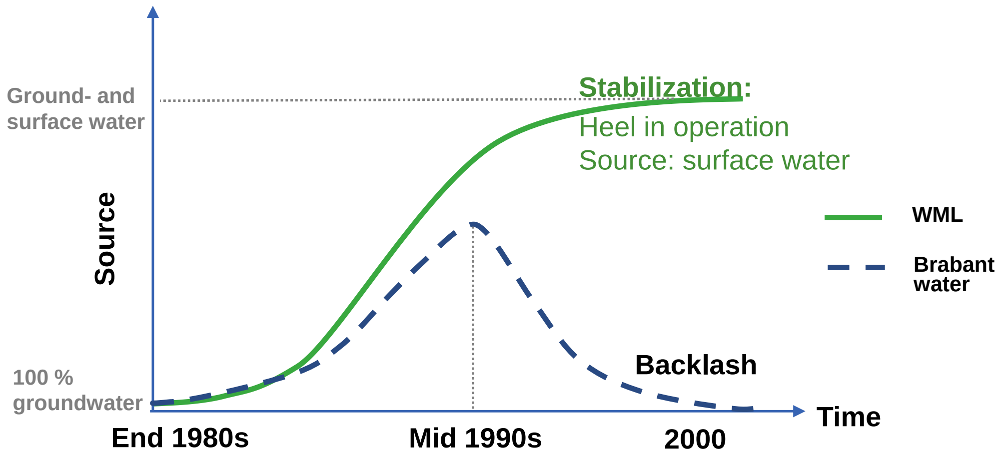

FIGURE 54 SCHEMATIC TRANSITION FOR THE TWO WATER COMPANIES.

17.3.6 Influencing the process

The stimulants for the transition came in part from the macro level and were hard for the water companies to influence.

At the provincial, national and European political levels there was a growing awareness that a limit had to be placed on the increasing rate of groundwater abstraction (for drinking water supply). On the one hand there was a fear of exhaustion or depletion of available groundwater resources, and, on the other, the adverse impact on the surroundings was becoming more and more evident.

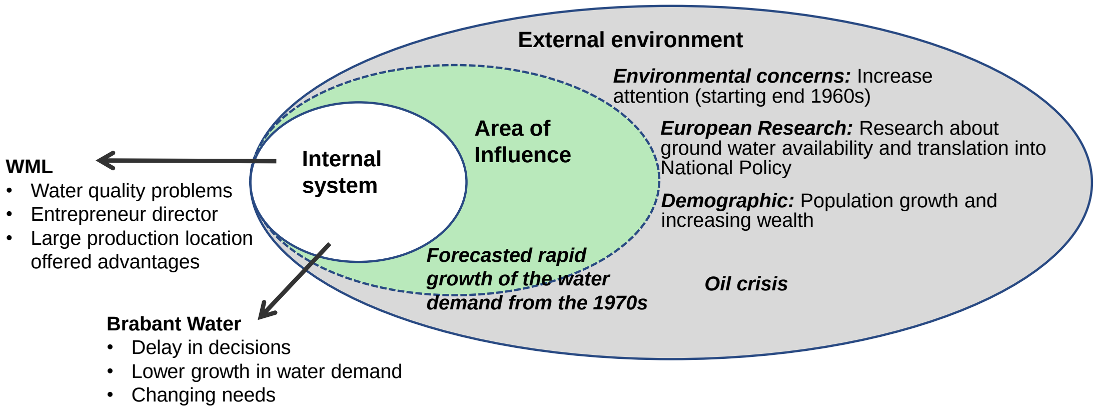

FIGURE 55 HISTORY AND PROGNOSIS OF DRINKING WATER DEMAND 1970 – 2025 (SOURCE: VEWIN DRINKING WATER STATISTICS 2008).

Water companies can influence the process by making different choices:

- WOB had a choice of a number of alternatives. The purchase of Biesbos water, via a pipeline, would have been a quick option which could probably have been implemented over a few years. By opting for PIM:
- control was kept in-hand
- a choice was made that came closest to the preferred source, namely, groundwater
- a choice was made for a long-term process, which still offered the possibilities of adjustments.
- At WML, director Huberts was a booster. He was very focused on up-scaling, cost-efficiency and the implementation of new techniques and innovation. The Heel project fit in well with his vision.
- Another factor was the internal drive at WML to close down a relatively small number of groundwater abstraction points which produced poor quality water. Solving these problems required investments. A large

treatment system on-site offered scale benefits in dealing with 5 or 6 small abstraction points. At WOB, the drive was essentially external: WOB itself had, at that time, no immediate problem with water supply or quality.

- WML and WOB, when applying for their licences, were committed to discussions and consultations with the community, for example, joint-recreational use of the terrain, and public consultation evenings.
- Following the revocation of the licences within the framework of the River Act, WOB submitted an appeal to the Council of State, which the latter dismissed.
- WOB influenced the process later on by setting up the Brede Kijk project. Together with the province and societal stakeholders, the company sought an integration of sustainability into water abstraction in the province.

In the sphere of influence the increasing water demand is situated between the transactional and external environment. Although, awareness campaigns were initiated from the water sector, the water companies actively searched for alternative sources to cope with the increasing demand.

17.4 Conclusion

This transition took approximately 20 years. Looking at the system as a socio-technic system, in this transitions different management decisions can be compared. We see that for one of the companies the transition was completely achieved while for the other ended in a backlash. The dynamics of the drivers can be also be clearly identified. In the 1990s the increasing water demand played an important role in the decision making. By the point that the transition was achieved the expected demand has completely changed, changes in the water system can be observed in decades.

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18 Discussion on transitions in the drinking water infrastructure

18.1 General discussion

In the last 100 years, we see that the water system has been gradually changed and adapted to new challenges and new demands. Although in the water system no radical changes have occurred, radical changes occur at sub-system level. For instance, at household level: modernizing the household pushed by energy availability had major influence in increasing water demand (Chapter 14) and development of new guidelines (Chapter 15). Additionally, fast growing demand influenced the plans of water companies regarding their water sources (Chapter 16). Also changes occur at water production facilities for instance by adapting new treatment technologies (Chapter 17).

Analysing the transition included determining the duration and extend of the changes, the drivers and the stakeholders involved. This analysis showed that there is inertia in the different levels (niche, regime and landscape). In general changes can be described in decades, but several decades are needed to identified notorious changes in the system. This inertia is linked to the dynamics of the different SEPTED dimensions, they change at different rate.

The analysis also indicates that the urban water system in the Netherlands has shown to be flexible, being able to cope with external changes, while keeping its functionality. System's inertia an system flexibility slow down the impact of the changes in magnitude and speed of the SEPTED dimensions, creating room to identify trends, analyse them and react. For instance, although gas penetration could be labelled as a "radical" transition for society by changing routines, the drinking water system adapted (see Chapter 6) and coped with the increase in water demand. Another sign for flexibility is the updating of guidelines and regulations. Radical transition in a sub-system, such as the transition to chlorine free water distribution, requires changes at different levels from water treatment to legal requirements, flexibility of different actors is also needed to be able to implement this type of transitions.

Keeping the system flexibility while monitoring changes in the SEPTED dimensions becomes crucial to cope with external changes. System flexibility does not only refer to physical flexibility, but also to the possibilities of working together with other stakeholders from the sphere of influence. Table 26 shows some of the changes in the SEPTED dimensions involved in the described transitions. Although there are "points of change", such as, health problems, or energy availability or energy crisis, the system takes time to change and adapt. As stated by Walker et al., 2013 "Guiding principles for the design of a sustainable adaptive plan are: explore a wide variety of relevant uncertainties, connect short-term targets to long-term goals over time, commit to short-term actions while keeping options open, and continuously monitor the world and take actions if necessary".

Water companies need not only to follow the trends in e.g. water use, but also understand how different SEPTED dimensions play a role in the changes in demand. For instance, new "luxury" showers can be promoted by producers. Although energy prices can limit the rate of penetration technological developments, such as, heat exchangers which reclaim heat from (shower) wastewater, can actually reinforce penetration of luxury showers.

TABLE 26 EXAMPLE OF DYNAMICS OF THE SEPTED DIMENSIONS OVER DIFFERENT PERIODS OF TIME

	1900-1960	1960-1990	1990-2013
Social	Wars	Wealth and comfort, establishing of consumer associations Health concerns e.g. THM discovery	
Economic	Economic limitations due to war	Energy price, wealth	
Political	Guidelines for dwellings	First guidelines for design of hot water systems	European policies, National plans
Technological		Diffusion of water devices in household	Diffusion of water saving appliances
Environmental		Energy availability and energy crisis.	water availability Environmental concern
Demographic		fast urbanization	

18.2 Drivers and rate of change (co-evolution and reinforcement)

(Water) infrastructure has become essential to urban life. At the beginning of 1900, the development of water infrastructure was focused on supplying the current water demand. With increasing knowledge and technology development and rapidly changing urban areas, planning became essential to guarantee a reliable service. For instance, estimating future drinking water demand and infrastructure performance involved large uncertainties, due to its dependence on several dynamic factors, e.g. demographics, technology developments, and policies. The analysis of the transitions showed that the drinking water infrastructure systems is in a continuous change due to transitions in the subsystems and in the external environment. Changes in the subsystems occur at different speed and driven by different factors.

By historically reviewing the transitions in the drinking water infrastructure in the Netherlands, we gained insight into the dynamic interactions of different dimensions, Table 26. Moreover we have gained insight into the inertia of the system and subsystems. For instance, over the last 60 years different drivers for change had an influence on the residential water use. Analysis of the transitions in the residential water consumption showed that different (f)actors and trends had a role in the change of routines, perceptions, and expectations. Over the period of time studied, the perception of comfort standards changed, as well as minimum requirements at the household level. External pressures such as the oil crisis in the 1970s and energy labelling of appliances and buildings have had an impact on residential water consumption. These pressures led to adjustments in regulative, normative, and cognitive aspects of regimes. Similar developments may be expected in the coming decades. Understanding the dynamics that influence residential water management may contribute to a better integration of water infrastructure planning by providing information on technology penetration, factors determining technology adoption, and interactions with other infrastructures, such as energy supply.

In the case of the water demand, the rate of installation of new appliances is relatively slow (approximately 60 years for full adoption of shower, or 20 years for 60% adoption of dishwasher), there is time for monitoring and reacting. Legislation and guidelines can be updated or revised in a decade, and decisions regarding changing the water source took approximately two decades. By monitoring trends and identifying key actors, drivers and barriers, water companies can identify possibilities to steer (technological) transitions to guarantee a reliable and sustainable system. Water companies can also decide to slow down the acceleration of transitions, Figure 7. This can be done by communicating with the users, users associations or technology providers, or by influencing regulations or guidelines, such as was shown in some of the described cases.

Transitions analysis also showed how different developments are interconnected, the so-called co-evolution. The transitions described in this rapport illustrate how changes are continuously taking place at different subsystems. These changes in the subsystems can reinforce or weaken each other, leading to changes in the system. For instance, the case of the raw water transition describes how the extraction subsystem is changed or adapted based on the trends and the expectations that drinking water demand will further increase. 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. Therefore changes have to be analysed having in mind the complete system. But the complexity of the system has to be understood, how, why and how fast are crucial questions which have to be answered per company to define and implement transition pathways.

Although it is expected that technology will support water use and monitoring of the (water) infrastructure systems, a more holistic, participatory, adaptive and forward-looking model of urban water management is needed. However, by understanding transitions and dynamics between different levels, sign posting becomes feasible. Sign posting can identify early warning signals that can lead to drastic changes and react/act accordingly to guarantee good functioning of systems. For instance growing penetration of luxurious shower heads is happening, which can be driven by increasing comfort, low price of drinking water and in the future maybe by heat recovery systems. By developing an integrated vision and understanding the dynamics of the urban water system, water companies can, to a given extend, steer the process and align the actors towards a more efficient urban water system.

18.3 Sphere of influence

In the different cases, different (f)actors in the sphere of influence could be identified, Figure 56. Interesting are the (f)actors that link the internal and transactional environment, and the transitional and the external system. Looking at a large period of time, changes in the system can be identified, as well as the possibilities of drinking water companies to steer the developments in the drinking water infrastructure. By acting pro-actively changes in legal standards and knowledge can be steered and in that way influencing the external environment in the long run. Additionally, user and users associations showed to be key actors in water demand changes. By identifying and communicating with these actors, and following the developments it is possible to prepare for the future by steering demand changes, new technology developments and new regulations.

Links with other sectors are also clear, in the studied cases. The energy nexus shows to be closely related to water demand and changes in guidelines. Links with other sectors, such as ICT, or other infrastructure should also be identified to find synergies in the urban environment.

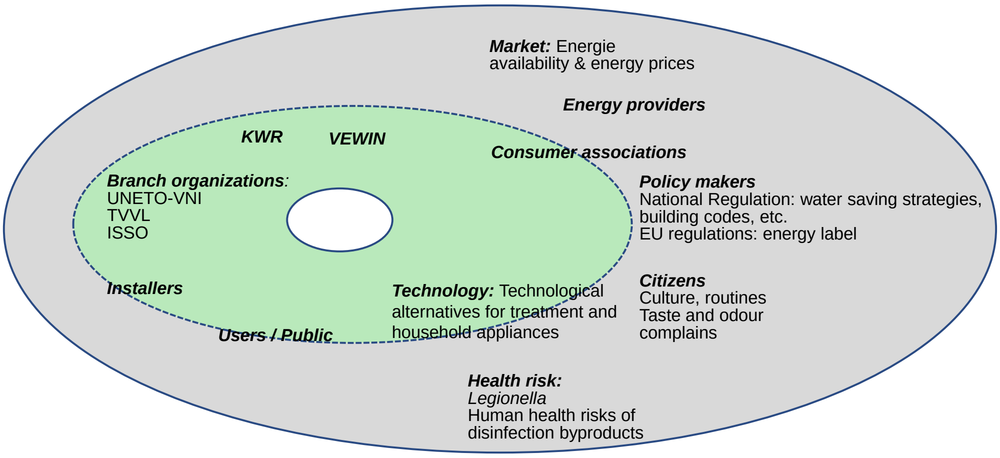

FIGURE 56 EXAMPLE OF SOME (F)ACTORS IN THE SPHERE OF INFLUENCED IDENTIFIED IN THE STUDIED CASES.

From the analysis of the four cases, we see that urban water systems are continuously changing. As expected, the transitions showed complex interactions between the SEPTED dimensions. Moreover, transitions are the result of a series of events that reinforce each other. Transitions start at different levels, from micro to macro level. Several stakeholders are involved in different stages of the transitions. Although, transitions involve long timeframes, major changes can be described in decades for the studied cases. Drinking water companies have played a role in all transitions studied. In some cases they have steered the process such as in the chlorine reduction or in the raw water transition.

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. 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 it requires processes of influence (i.e. steering, facilitation and coordination). This has been shown in the cases, in which users, researchers, etc., work together towards more safe and efficient systems.

Therefore, identifying the sphere of influence supports the process 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. From the studied cases, lessons are learned, for instance about how future expectations can influence decision making, as in the case of shifting raw water sources.
In effect, transition management requires identifying the long and medium term of the SEPTED dimensions, understanding the dynamics of the different regimes and creating space for frontrunners in so-called transition arenas, to drive activities in a shared and desired direction (vision).

As shown in the previous section, transition processes are complex, involve long timeframes, include multiple factors and multiple actors and occur across multiple levels. Transitions are the result of mutually reinforcing socio-technical change occurring through a variety of processes across technological, cultural, institutional, economic and ecological spheres of society (Schot and Geels 2007). The underlying assumption is that while full control and management of transitions is impossible, it is possible to ‘manage’ transitions in terms of adjusting, adapting and influencing the direction and pace (Rotmans and Loorbach 2007). Expectations and social visions play an active role in shaping innovative activities and influencing the technological transitions. A clear example is the increasing expectation for comfort. Expectations are important in the process of aligning actors around common goals. Shared expectations help to establish a common agenda, thus strengthening innovation. A good example of the steering transition is the reduction of water consumption in the 90s which was supported by different means: more efficient technologies, awareness campaigns and legislation. Expectations are also critical in the establishment of niches, or 'protected spaces', in which new technologies can develop. Consequently, transitions on urban water management cannot be managed by traditional top-down practices, but instead require processes of influence (i.e. steering, facilitation and coordination). Managing transition reforms must focus on facilitating cognitive and normative change, alongside regulatory measures and structural change (Farrelly and Brown 2011).

18.4 Drinking water infrastructure as a socio-technical system

The analysis of the four transitions confirmed that transitions are not stand alone events, but they can reinforce or disrupt other parallel transitions. Table 27 shows different aspects of the drinking water system as a socio-technical system, which were identified in the cases.

TABLE 27 DIFFERENT SOCIO-TECHNICAL CHARACTERISTICS IDENTIFIED IN THIS STUDY

	Socio-technical characteristics	Examples in the studied cases
1	Elements of surprise due to the unpredictable nature of the system	Gas availability pushed showers diffusion. Health risk, e.g. legionella of discovering of THM boosted research and innovation
2	Emergence of macro-scale properties from micro-scale interactions	From the water sector: new legislation and standards Guidelines from warm water
3	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	Influence of changes in demand in water source, treatment but also in design of hot water systems. Or energy influence, due to gas availability, or oil crisis.
4	Self-organisation, or the emergence of order/complexity without inputs from the outside	Within 50 years new legislation was adopted, for design of water installations. Cooperation in the research phase in the Chlorine case.
5	Feedbacks and thresholds; or non-state equilibriums that change over time and which generate dynamic processes with stable and unstable regions	Search for new sources. The complete shift in water demand, from a growing demand trend to a reducing demand trend.

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