BTO 2015.051 | October 2015

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

KWR Watercycle Research Institute

BTO

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

BTO 2015.051 | September 2015

Project number
400695-045

Project manager
MSc. J.W. (Jan Willem) Kooiman

Client
BTO - Exploratory research

Quality Assurance
prof PhD. G.J. (Gertjan) Medema

Author(s)
PhD MSc. C.M. (Claudia) Agudelo-Vera,
MSc. C.H. (Chris) Büscher,
MSc MTD. L.J. (Luc) Palmen,
ing. I. (Inke) Leunk,
PhD MSc. E.J.M. (Mirjam) Blokker.

Sent to
This report is distributed to BTO-participants and is public.

PO Box 1072
3430 BB Nieuwegein
The Netherlands

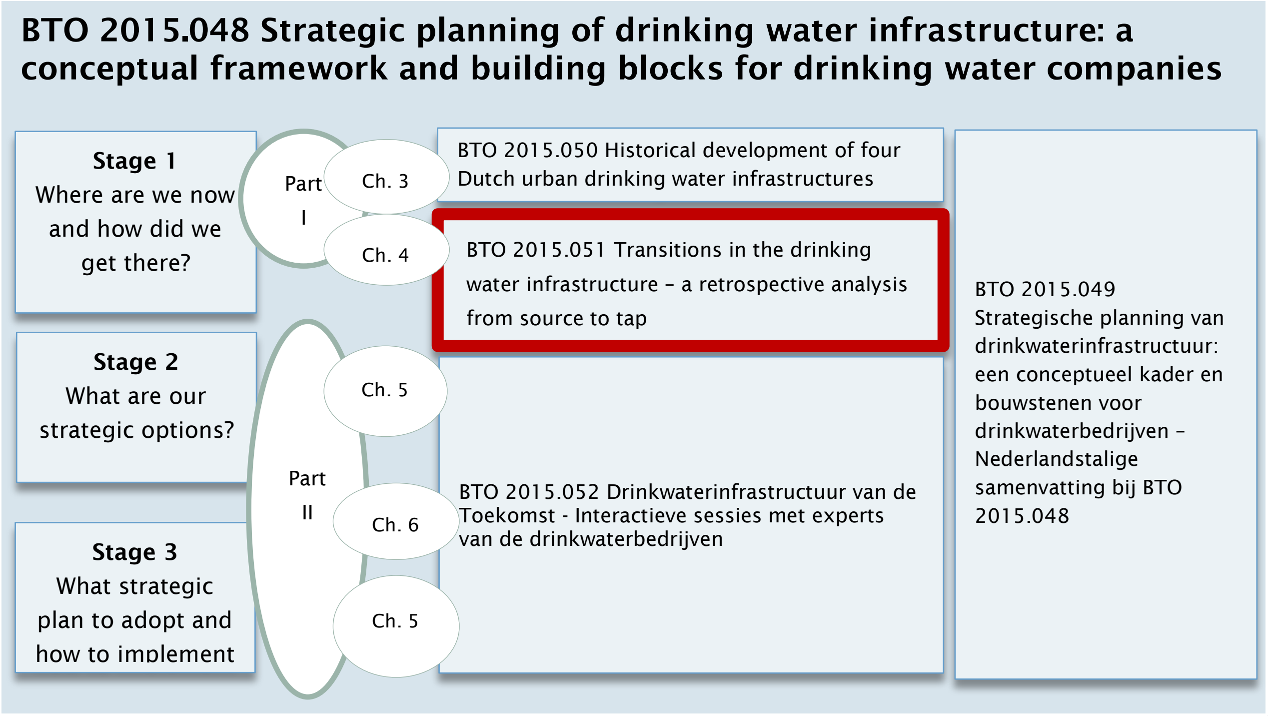
T +31 (0)30 60 69 511
F +31 (0)30 60 61 165
E info@kwrwater.nl
I www.kwrwater.nl

Watercycle
Research
Institute

BTO 2015.051 | October 2015 © KWR

Foreword

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



Summary

This report describes the results of a study into past transitions in drinking water infrastructure. Four case studies have been carried out, each describing a transition relating to a specific part of drinking water infrastructure and the role of drinking water companies in these transitions. This study is part of the project 'drinking water infrastructure of the future', in which critical insights and lessons learned from past transitions will be used in exploring plausible future transitions. The four case studies included transitions in the residential water consumption in the Netherlands, transitions in the design of (hot) drinking water installations, transition to minimum chlorine usage in drinking water production in The Netherlands and a transition from groundwater to surface water in one water production facility.

The research questions were the same in each of these cases, namely: what were the changes that occurred, what were the main drivers and who were the main actors behind these changes? More specifically, the objectives of this study were to identify and to better understand:

- The type of change and timespan of and actors involved in the transition, as well as the main drivers/trends influencing the transition.
- The relation between the physical and social aspects concerning drinking water infrastructure.
- The extent to which drinking water companies themselves influenced water infrastructure's development so as to derive the most promising possibilities for steering future transitions.

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

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

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

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. Transitions in the drinking water system are relatively slow. 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 adoption of water saving toilets 40 years. In this specific case changes in demand were parallel first to trends regarding the modernization of the household and afterwards more efficient water appliances. The changes found in this analysis showed that we can describe these changes in decades.

The transition towards chlorine free network and updating the hot water guidelines are clear examples of how water companies can steer and accelerate transitions towards desirable paths. Steering and acceleration in these case was possible by establishing strategic alliances with partners from the sphere of influence. Moreover the analysis only showed incremental changes. Regarding the role of the drinking water companies, the retrospective analysis shows that in the case of changing residential water demand the role of drinking water companies is less evident than in the case of reducing the chlorine use in the Netherlands. Regarding changes in demand, the water companies have accepted the changes in demand and have been willing to cater for it. While other (f)actors have strongly influence changes in demand e.g. stimulating energy saving appliances. Energy has played an important role in the changes of the residential water demand is hot water demand. The availability of energy led to an increase in demand specially due to increase of shower penetration and shower frequency and the (threat of) scarcity of fuel and wish for sustainability are driving the decrease of demand.

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. This information is key to achieve goals.

To steer transitions in the drinking water system, it is required the active use of the sphere of influence, in order to optimize the system but also to consider changes in other landscape elements which may drive changes in the internal system.

Innovation is crucial for transitioning. Innovation not only comprises new technology, but also new forms of organization, new practices, and new insights on global and local concerns. In the studied cases, innovation is present by new technologies in water appliances, in new R&D in the case of chlorine, in new perspectives in the case of the raw water.

Different ways to influence a transition. By identifying drivers, key players transitions can be accelerated. As main conclusion, there is room for the drinking water companies to monitor and steer transitions by using their sphere of influence. Changes occur continually, taking part in the transition is a choice. By being involve in shaping transitions influence can be exert. In this case, the rate of the changes is relatively low (decades) which offer possibilities to identify different transitional pathways. However this can also represent a drawback because the system is not able to changed faster. Therefore, future desirable system configuration have to be planned considering the inherent inertia of the system (including users, legislation, technologies, etc.). Furthermore, analysis at system level are required to identify interrelations (e.g. demand and extraction). By not actively taking part in the sphere of influence, water companies allow other stakeholders to steer the transitions.

Contents

1 Introduction 8

2 Theory of transitions in socio-technical systems applied to the drinking water infrastructure 10
2.1 Introduction 10
2.2 The socio-technical regime 11
2.3 Describing transitions of socio-technical systems 12
2.4 The Multi-level perspective 12
2.5 Sphere of influence 14
2.6 References 15

3 Transitions in Residential Water Consumption in the Netherlands 17
3.1 Introduction 17
3.2 Analysing the transitions 22
3.3 Discussion 25
3.4 Conclusions 26
3.5 References 26

4 Transition in the design of drinking water and hot water installations 29
4.1 Introduction 29
4.2 Transition towards new guidelines for efficient water-energy design at the building level 30
4.3 Analysing the transtion 33
4.4 Conclusion 35
4.5 References 35

5 Transition to a minimum chlorine usage in the drinking water production in the Netherlands 37
5.1 Introduction 37
5.2 Method 38
5.3 Analysign the transition 40
5.4 Conclusion 46
5.5 References 47

6 Raw water transition 49
6.1 Theoretical framework 49
6.2 Method 49
6.3 Describing the transition 49
6.4 Conclusion 62
6.5 References 62

7 Discussion 63
7.1 General discussion 63

7.2 Drivers and rate of change (co-evolution and reinforcement) 64
7.3 Sphere of influence 65
7.4 Drinking water infrastructure as a socio-technical system 67

1 Introduction

In the Netherlands, drinking water infrastructure and sewer systems were built since the 19th century to solve hygiene issues and this led to a significant reduction of several diseases, (Geels, 2005). As the population grew the system has been extended but no radical changes were introduced from the first design practice. The Dutch drinking water sector now has changed from the building stage to a maintenance stage. It has to operate in a society which is changing much faster than ever before and with climate change induced challenges to maintain a healthy system at affordable costs. This may require more radical changes. Now may be the time to prepare for that, as changes, however radical, will take time.

How can we prepare for the future? What are the options? What is our starting point? How can we get from the starting point to the new situation? There are technical and societal challenges. Who do we need to cooperate with? The first step in answering these questions is looking at the past. What can we learn from past transitions and past investments? What were drivers for changes? How can we use that to enforce future changes, even more radical changes?

This report describes the outcomes of a study into past transitions within the drinking water infrastructure in the Netherlands. Chapter 2 describes the theory of transitions in socio-technical systems. Chapters 3-6 describe four case studies, each one focusing on a transition relating to a different part of the drinking water infrastructure, from source to tap. Chapter 3 describes how changes in society and the modernization of the household led to changes in water demand. Chapter 4 describes the transition in the design of (hot) drinking water installations. An important transition that the Dutch water companies induced themselves is the transition towards a minimum chlorine usage in drinking water production in The Netherlands. Chapter 5 describes how, within their sphere of influence, the water companies were able to enforce this transition in a few decades nationwide. Chapter 6 describes how a relatively radical change towards a new source could occur at one company and how it did not happen at another. The last chapter discusses some overall findings of all the four cases.

The main research question was the same in each of these cases, namely: what were the changes that occurred, what were the main drivers and who were the main actors behind these changes (leading or not leading up to a transition)? More specifically, the objectives of this study were to identify and to better understand:

- The type of change and timespan of and actors involved in the transition, as well as the main drivers/trends influencing the transition
- The relation between the physical and social aspects concerning drinking water infrastructure
- The extent to which drinking water companies themselves influenced water infrastructure's development so as to derive the most promising possibilities for steering transitions

The questions and objectives are in line with how drinking water infrastructure is defined and studied. Drinking water infrastructure in this study is conceived of as inherently a socio-technical system. This means that water infrastructure comprises of physical and technological components, such as treatment and distribution infrastructure, but is shaped by and itself shapes social and organisational processes for instance relating to the design, implementation and management of these systems. These different sociotechnical components are in continuous interaction and subject to (dynamic) pressure of the external environment, shaping and resulting in transitions. When describing the transition, special focus was given to the drivers of the transitions, the time span when the transition took place and the actors involved. These descriptions included the so-called SEPTED dimensions of development: social, economic, political, technological, ecological and demographic aspects. The multi-level perspective (MLP) described by Geels (2002) is used, which distinguishes between three levels: niche-innovations, sociotechnical regimes and sociotechnical landscape.

A concurrent study also examined past transitions with respect to drinking water infrastructure, but examined integrally water infrastructures' development in four urban areas over the past century[1]. Combined, but from different angles, these two studies seek to derive critical insights and lessons from past transitions that can be used when thinking about and planning for future transitions in drinking water infrastructure. As such, the two studies generate input for the overarching project they are part of, titled 'drinking water infrastructure of the future'. Although the general focus of this project is indeed on the future of drinking water infrastructure, it is assumed that the future is -at least partly- entwined with and shaped by developments of the past and present, which is precisely why the two studies on past transitions have been undertaken.

The insights and outcomes of this and the other study on past transitions are thus useful in their own respect, but also explicitly inform the subsequent stage of this project, in which plausible future scenarios for the city are construed. These scenarios are used to support drinking water companies in their strategic planning processes, by assessing the robustness of their strategic choices regarding their drinking water infrastructure in light of those scenarios. For more details, please read the main report: "BTO 2015.048 Strategic planning of drinking water infrastructure: a conceptual framework and building blocks for drinking water companies".

---

[1] See report BTO 2015.050 Historical development of four Dutch urban drinking water infrastructures.

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

2.1 Introduction

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

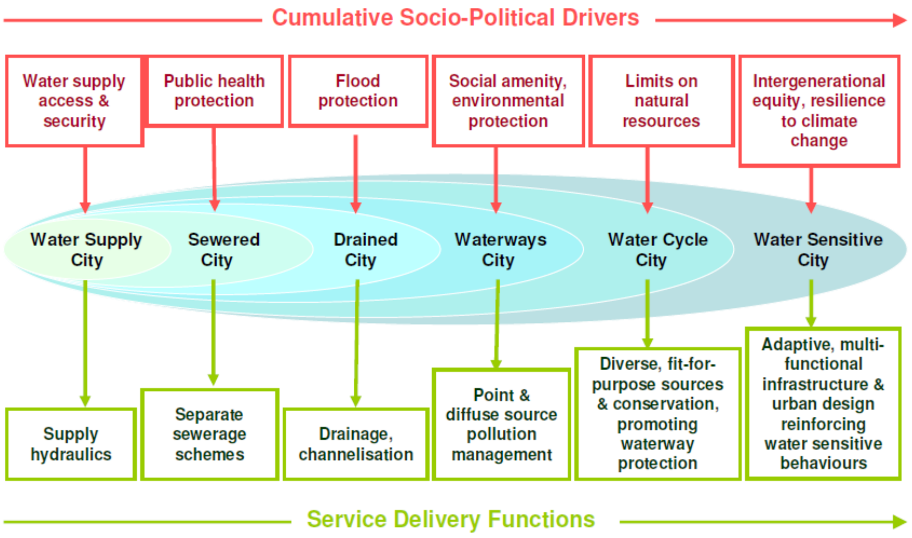


Figure 1 Transitions in urban water infrastructure (Brown et al., 2009)

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

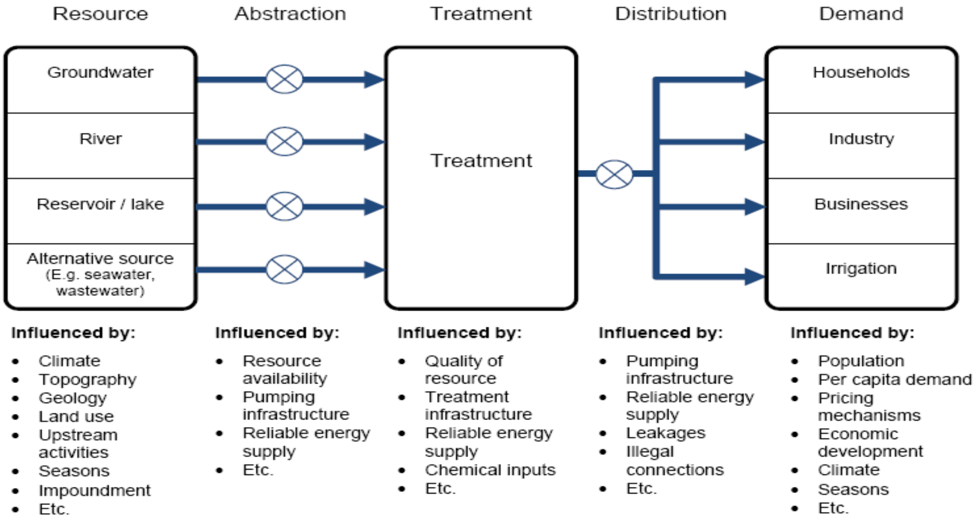


Figure 2 Schematic representation of the drinking water distribution system - from source to tap - and influential factors - drivers, (ICLEI, 201).

2.2 The socio-technical regime

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

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

Socio-technical systems display most of the following features:

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

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

2.3 Describing transitions of socio-technical systems

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

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

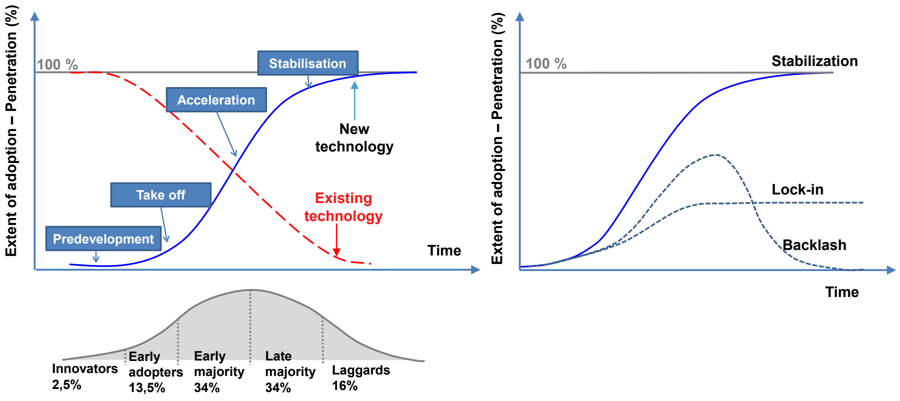


Figure 3 *Schematic description of transition trajectories a) successful transition, b) restricted or failed transition trajectories (After Rotmans et al., 2001)*

2.4 The Multi-level perspective

We use the multi-level perspective (MLP) to analyse the socio technical transitions (Geels 2002). The MLP distinguishes three levels: niche-innovations, sociotechnical regimes and sociotechnical landscape, 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 comes as a result of interactions between the three levels. The landscape at the macro level provides long term gradients for the established sociotechnical regime where technologies develop incrementally, and for the niche(s) where radical innovations incubate and proliferate. The dynamic stability of the regime can be perturbed by innovations that develop in niches, pressures from the landscape that act on the regime, or from the build-up of internal regime tensions. Social groups within the regime can mount an endogenous response to absorb the pressures and/or niche innovations. In some cases however, this response to persistent problems/pressures, is not sufficient and a system transition to a completely new regime takes place. In a transition, the prevailing attitudes, practices of technology production, and its use in the system are gradually substituted by new ones that originate in niches – novel small scale sociotechnical systems (Schot and Geels 2007), see Figure 4a.

Table 1 Description of the three levels of the MLP (Geels 2002)

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

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

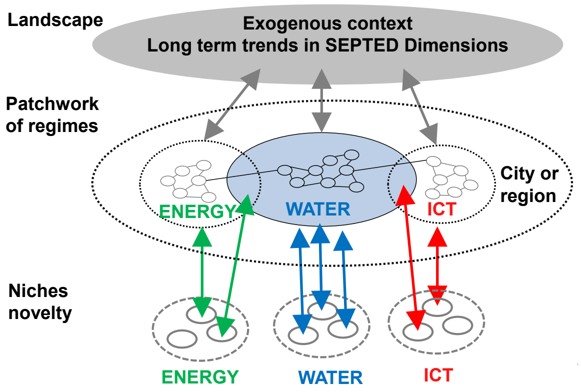
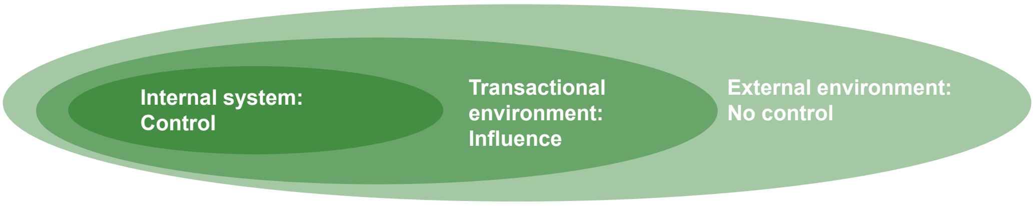


Figure 4 Schematic representation of the Multi-level perspective (MLP) for this study, interactions between the infrastructure regimes in the city and the niches and landscape.

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

2.5 Sphere of influence

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



Internal system: aspects of water infrastructure that water company controls

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

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

Figure 5 Defining system boundaries for Water Infrastructure (WI) (After Gharajedaghi, 1999)

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

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

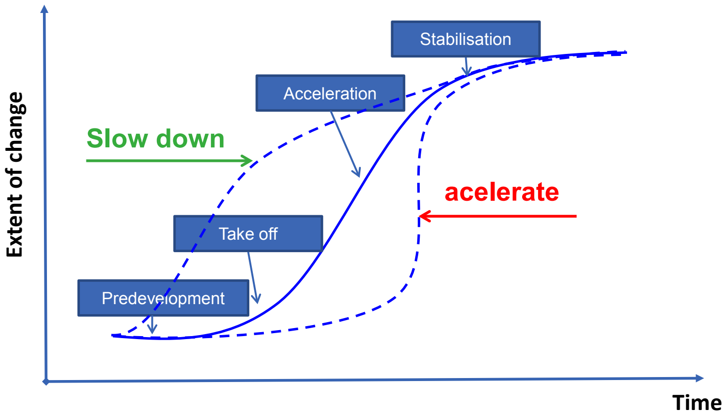


Figure 6 Possible development pathways in a transition process

2.6 References

Brown, R. R., Keath, N. and Wong, T.H.F. 2009. Urban water management in cities: historical, current and future regimes. 59: 847-855.

Geels, F. W. 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy 31(8–9): 1257-1274.

Geels, F. W. 2004. From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. Research Policy 33(6-7): 897-920.

Geels, F. 2005. Co-evolution of technology and society: The transition in water supply and personal hygiene in the Netherlands (1850–1930)—a case study in multi-level perspective. Technology in Society, 27(3), 363-397.

ICLEI,2011. SWITCH Training Kit. Ed. Philip, R.; Anton, B.; Loftus, A. Module 3 – Water Supply. http://www.switchtraining.eu/fileadmin/template/projects/switch_training/files/Modules/Module_reduced_size/Switch_Training_Kit_Module_3.pdf

McDowall, W. 2012. "Technology roadmaps for transition management: The case of hydrogen energy." Technological Forecasting and Social Change 79(3): 530-542.

Papachristos, G., Sofianos, A., Adamides, E. 2013. System interactions in socio-technical transitions: Extending the multi-level perspective. Environmental Innovation and Societal Transitions 7(0): 53-69.

Rotmans, J., Kemp, R. 2003. Managing Societal Transitions: Dilemmas and Uncertainties: The Dutch energy case-study.

Rotmans, J., Kemp, R., Van Asselt, M. 2001. More evolution than revolution: Transition management in public policy. Foresight, 3(1), 15-31.

Schot, J. and Geels, F. W. 2007. "Niches in evolutionary theories of technical change: A critical survey of the literature." Journal of Evolutionary Economics 17(5): 605-622.

3 Transitions in Residential Water Consumption in the Netherlands[2]

3.1 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 7. Not only changes in the total demand have taken place, but also the water use per activity, Figure 8. To understand the changes in demand per activity, Figure 9 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 3a. 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 9). 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.

---

[2] 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.

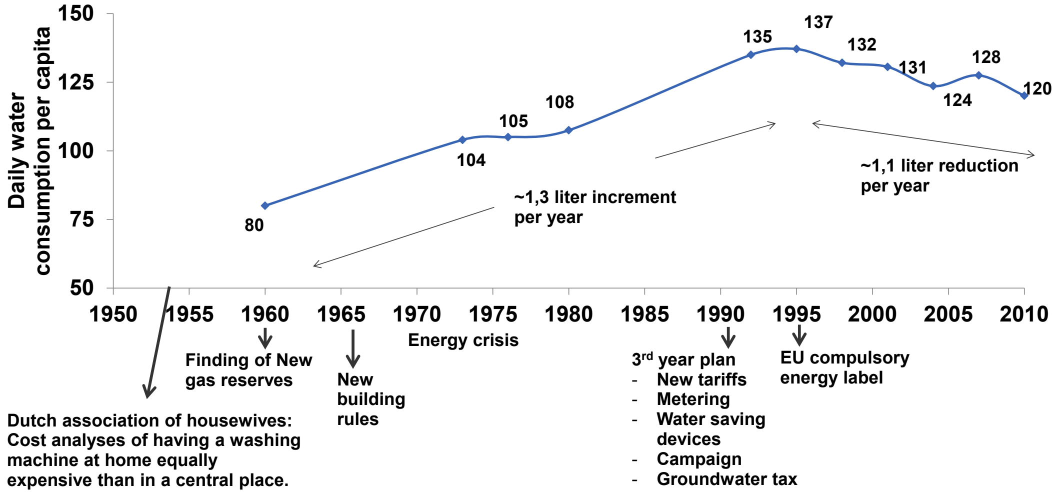


Figure 7 Overview of the changes in the total and residential water consumption per person per year, in the Netherlands and the main drivers

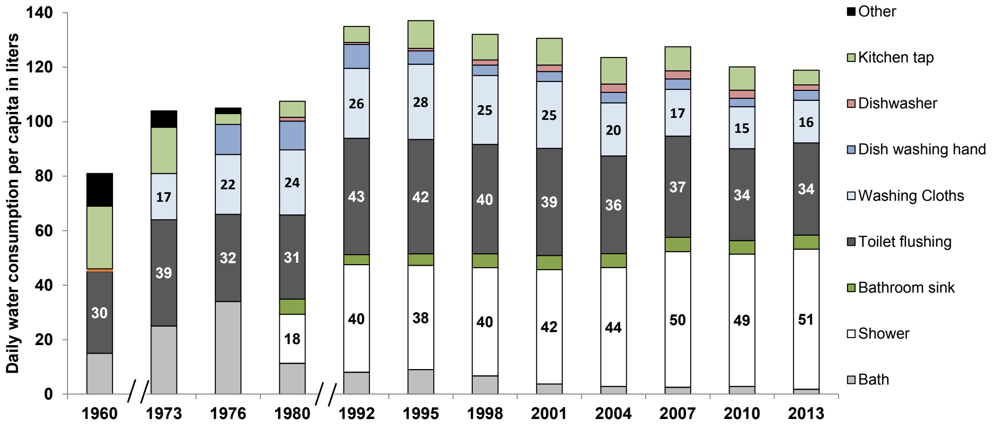


Figure 8 Residential water consumption per capita since 1960

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)

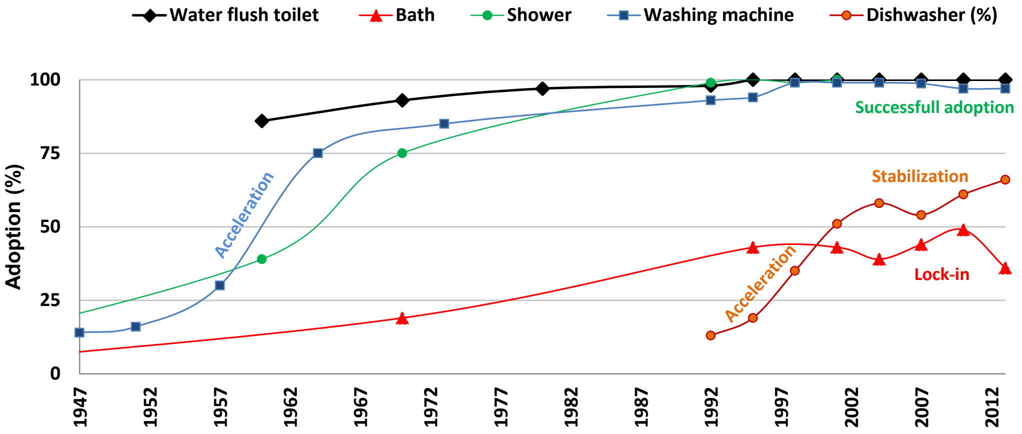


Figure 9 Overview of the adoption of residential water appliances

3.1.1 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 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.

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 2. 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 2 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		

3.1.2 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[3] 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 9. 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 ° 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.

3.1.3 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 8. In 1991 the third 10 year plan of the government was established. Within the action plan six measures were

---

[3] Gasunie is a Dutch gas infrastructure company

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 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[4] was formed. In 1994 guidelines for drinking water systems in households[5] 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[6]. 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 10a. 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 10b. 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 3).

---

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

[5] ISSO - 30 Tapwaterinstallaties in woningen

[6] Aanpak Warmwaterbesparing

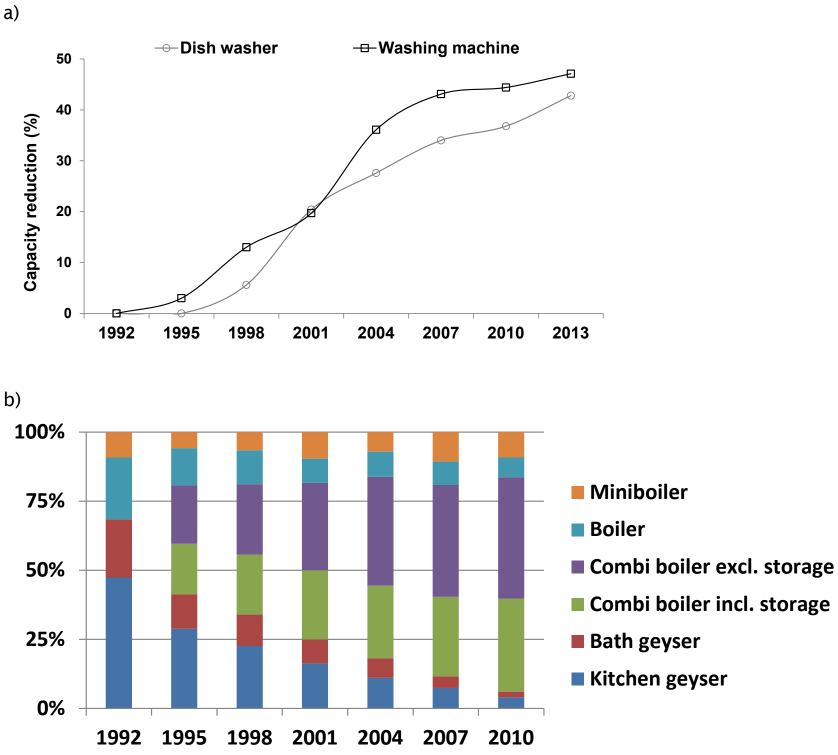


Figure 10 Transition towards more efficient energy efficient appliances in the last two decades a) reduction of the capacity of washing machine and dishwasher machine, b) transition of the market penetration of different hot water systems at residential level.

3.2 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 11 shows the dynamics involved in daily water consumption for shower, which, according to Figure 8, was approximately 40 lcp in the 1990s and in the last decade is approximately 50 lcp. Figure 11 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 11a) and ii) frequency, (Figure 11c). 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 11b). Although, shower average capacity seems rather stable, technology transition is constantly taking place. Figure 11b 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 3.

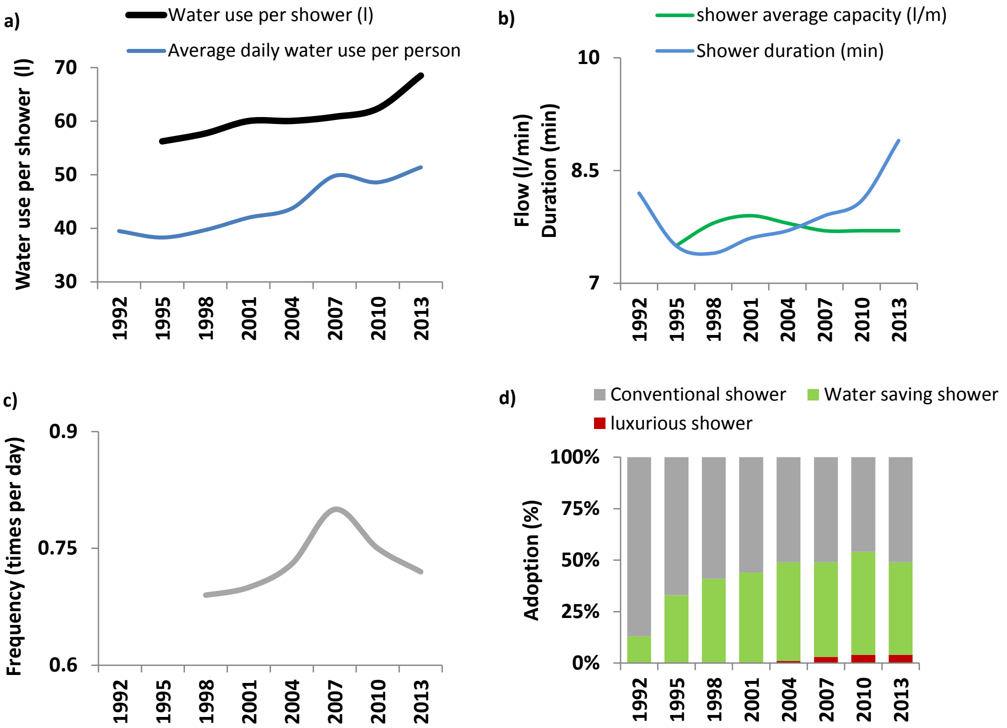


Figure 11 Transition towards more efficient energy efficient appliances in the last two decades a) reduction of the capacity of washing machine and dishwasher machine, b) transition of the market penetration of different hot water systems at residential level.

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 12.

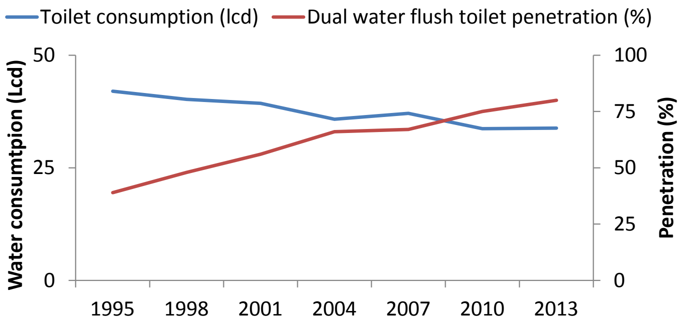


Figure 12 Daily water consumption per capita for toilet flushing and diffusion of water saving toilets (dual water flush).

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 13. Moreover, the role and influence of the different actors may change over time. Figure 13 shows the main drivers and actors, involved in the residential water demand transitions.

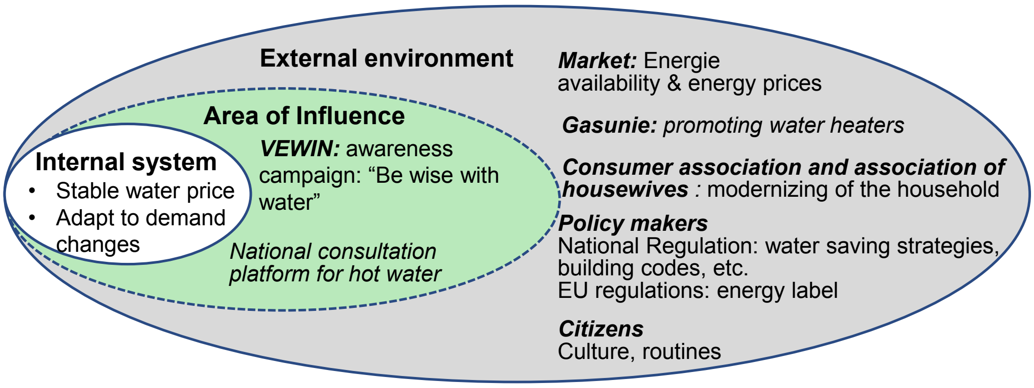


Figure 13 Sphere of influence of the transition in residential water consumption.

3.3 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.

3.4 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.

3.5 References

Agudelo-Vera, C.M., Blokker, E.J.M., Pieterse-Quirijns, E.J., Scheffer, W. 2014. Water and energy nexus at the building level. in: REHVA European HVAC Journal, pp. 12-15.

Agudelo-Vera, C.M., Blokker, E.J.M., Büscher, C.H., Vreeburg, J.H.G. (In Press). Analysing the dynamics of transitions in residential water consumption in the Netherlands. Water Science & Technology: Water Supply.

Arbués, F., M. A. García-Valiñas, et al. (2003). "Estimation of residential water demand: A state-of-the-art review." Journal of Socio-Economics 32(1): 81-102.

Blokker, E. J. M. van Osch, A. M. Hogeveen, R. and Mudde C.(2013). Thermal energy from drinking water and cost benefit analysis for an entire city. Journal of Water and Climate Change 4(1): 11–16.

CBS (2012). Environmental accounts of the Netherlands 2011. The Hague/Heerlen.

CCD (1967). De toekomstige drinkwatervoorsiening van Nederland. Centrale Commissie voor Drinkwatervoorziening. 's-Gravenhage.

Correljé, A. and T. Schuetza (2012). Decentral water supply and sanitation. Inverse Infrastructures. T. M. Egyedi and D. C. Mehos. UK.

CUWVO/STORA (1976). Volume correctie.

de Moel, P. J., J. Q. J. C. Verberk, et al. (2012). Drinking water principles and practice.

Farrelly, M. and R. Brown (2011). "Rethinking urban water management: Experimentation as a way forward?" Global Environmental Change 21(2): 721-732.

Foekema, H., E. Duijser, et al. (2004). het drinkwatergebruik thuis 2004. Amsterdam, TNS NIPO.

Foekema, H. and O. Engelsma (2001). Het waterverbruik thuis 2001. TNS NIPO. Amsterdam. Report number A8324.

Foekema, H. and R. Lenselink (1999). Nederlanders gaan zuiniger met water om. VEWIN. Rijswijk.

Foekema, H. and L. van Thiel (2011). Watergebruik thuis 2010. TNS NIPO. VEWIN. Amsterdam. Rapport number C7455.

Foekema, H., L. van Thiel, et al. (2008). Watergebruik thuis 2007. T. NIPO. Amsterdam. Rapport number C6026.

Geels, F. W. (2002). "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study." Research Policy 31(8–9): 1257-1274.

Geels, F. W. (2004). "From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory." Research Policy 33(6-7): 897-920.

Harpman, L. (1940). "‘Onderwerpen die aandacht vragen! De badgelegenheid in de arbeiderswoning’." Economisch Technisch Tijdschrift 20(6): 62-64.

Kanne, P. (2005). Watergebruik thuis 2004. VEWIM. Rapport number C4628.

Krozer, Y., S. Hophmayer-Tokich, et al. (2010). "Innovations in the water chain - experiences in The Netherlands." Journal of Cleaner Production 18(5): 439-446.

Liebregts, M. (2011). "Ontwikkeling woonkwaliteit: van 1960 tot 1990." Retrieved 20 September 2013, from http://www.bestaandewoningbouw.nl/ontwikkeling-woonkwaliteit-periode-van-1960-tot-1990/.

McDowall, W. (2012). "Technology roadmaps for transition management: The case of hydrogen energy." Technological Forecasting and Social Change 79(3): 530-542.

Naarding, C. J., H. A. Flendrig, et al. (1970). "Warm water in de woning." Gas 90: 46-50.

Overbeeke, P. v. (2001). Kachels, geisers en fornuizen - Keuzeprocessen en energieverbruik in Nederlandse huishoudens 1920-1975. PhD., Technical University Eindhoven.

Rotmans, J. and D. Loorbach (2007). Transition management: reflexive steering of societal complexity through searching, learning and experimenting. The Transition to Renewable Energy: Theory and Practice. J. C. J. M. V. d. Bergh and F. R. Bruinsma.

Schot, J. and F. W. Geels (2007). "Niches in evolutionary theories of technical change: A critical survey of the literature." Journal of Evolutionary Economics 17(5): 605-622.

STORA (1980). Woningbezetting, waterverbruik en huishoudelijke waterverontreiniging: 39.

van Dorst, C. (2007). Tobben met de was : een techniekgeschiedenis van het wassen in Nederland 1890-1968. PhD., Technical University Eindhoven.

Vogelzang I. (1956) De drinkwatervoorziening van nederland voor de aanleg van de drinkwaterleidingen (Drinking water systems in the netherlands before the construction of piped water). PhD thesis. Utrecht: Rijksuniversiteit Utrecht.

van Thiel (2014). Watergebruik thuis 2013. TNS NIPO. VEWIN. Amsterdam. Rapport number C5707.

VEWIN (2004). Waterleidingstatistiek 2003 (In Dutch). Rijswijk.

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

4.1 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 3, 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 14 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.

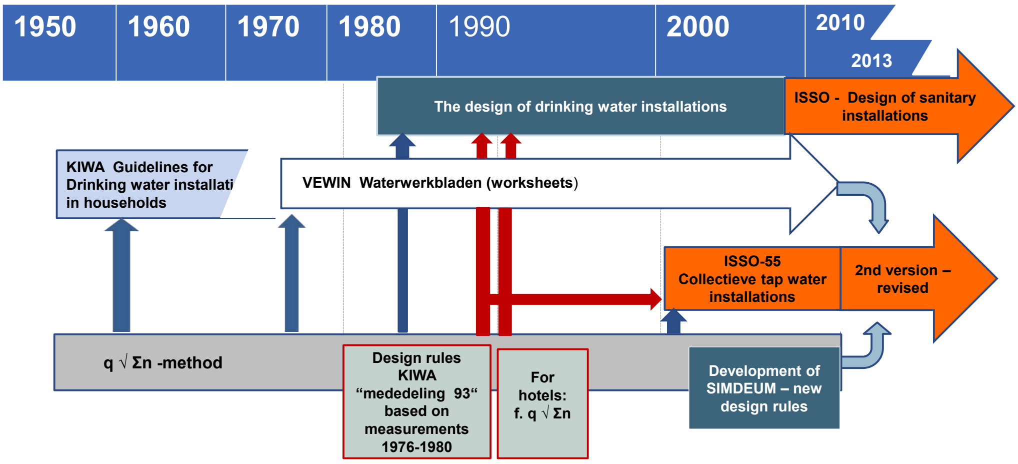


Figure 14 Overview of available methods and guidelines in the Netherlands.

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.

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

4.2.1 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.

4.2.2 Late 2000s until now

4.2.2.1 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 15. With this tool, customize calculation of the peaks required for an optimal design of water installations was possible.

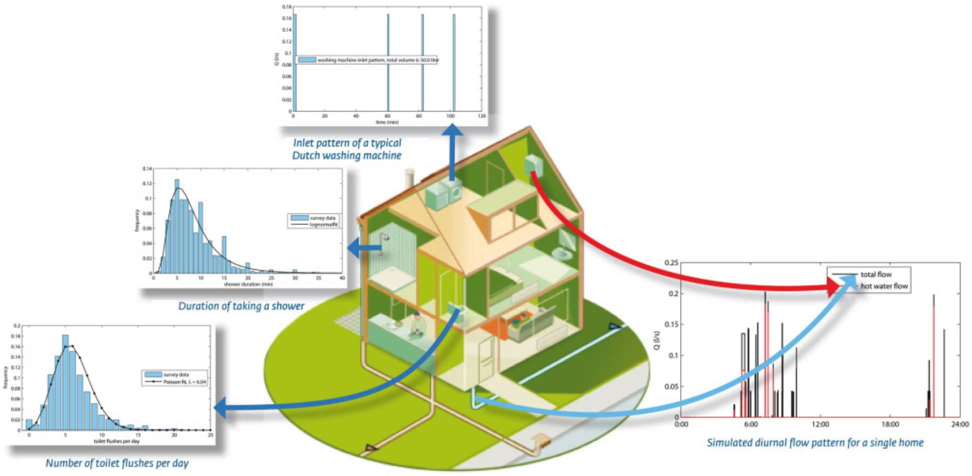


Figure 15 Schematic representation of the simulations with SIMDEUM

4.2.2.2 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[7]. 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.

4.2.2.3 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

---

[7] 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

equations, the SIMDEUM simulated standardised buildings, is solid. The results for a business hotel are presented in Figure 16, showing the measured and simulated cold and hot water flow.

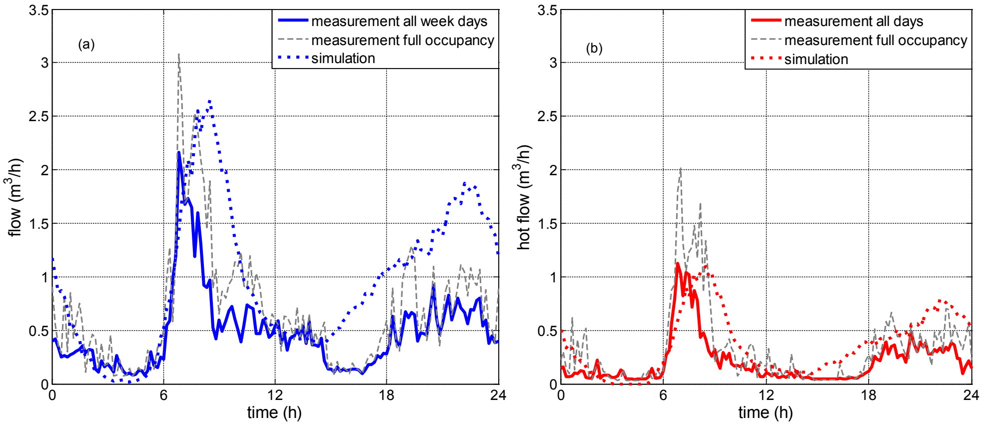


Figure 16 Comparing average measured and simulated demand of a) cold water and b) hot water of a business hotel

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 17 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.

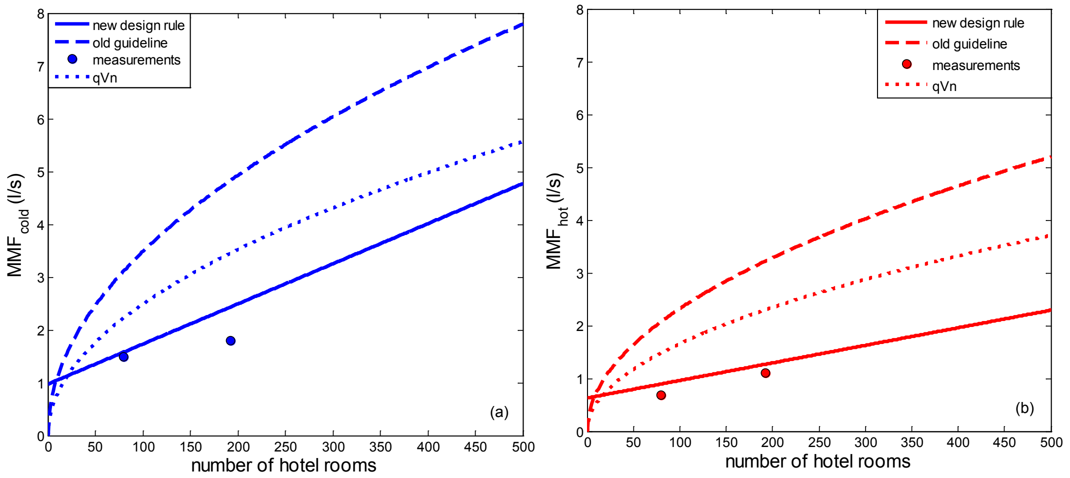


Figure 17 Comparing measured and simulated peak flows a) cold water and b) hot water of a business hotel

4.2.2.4Consequences 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 18 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.

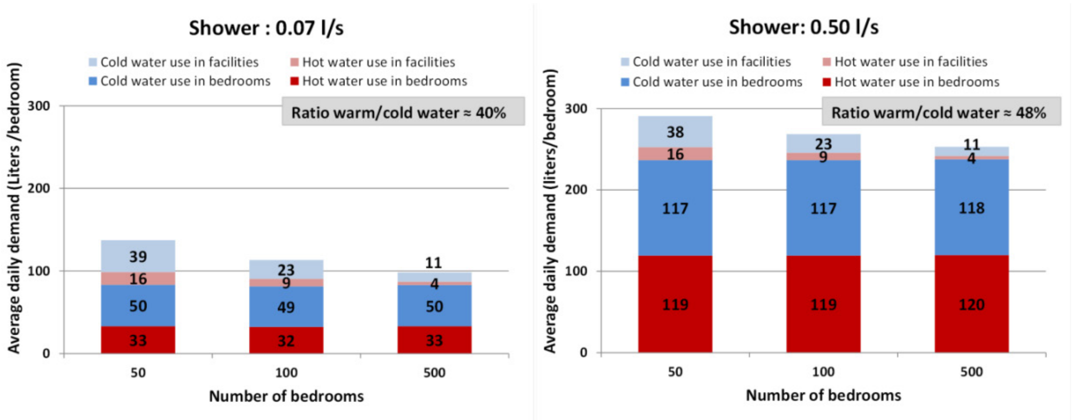


Figure 18 Variations in the daily water use in a business hotel according number of bedrooms. a) for a water saving shower head and b) for a luxurious shower head.

4.3 Analysing the transtion

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 19 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.

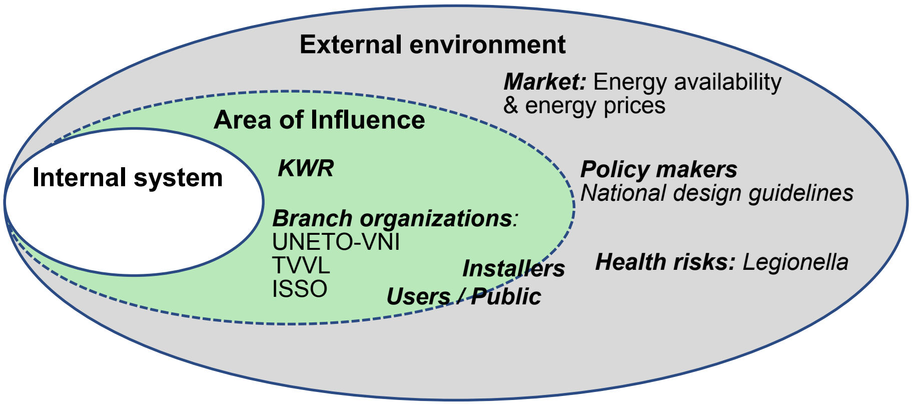


Figure 19 Sphere of influence of the transition towards new design guidelines for hot water installations.

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.

4.4 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.

4.5 References

Agudelo-Vera, C.M., Blokker, E.J.M., Pieterse-Quirijns, E.J., Scheffer, W. 2014. Water and energy nexus at the building level. in: REHVA European HVAC Journal, pp. 12-15.

Blokker, E.J.M. and Van der Schee, W.: Simulation of water demands provides insight, Water Supply and Drainage for Buildings, CIB W062, Taipee, Taiwan, 18-20 September, 2006.

Blokker, E. J. M., Pieterse-Quirijns, E. J., Vreeburg, J. H. G. and van Dijk, J. C. (2011). Simulating nonresidential water demand with a stochastic end-use model. Journal of Water Resources Planning and Management, 137(6), 511-520.

Blokker, E. J. M., van Osch, A. M., Hogeveen, R. and Mudde, C. (2013). Thermal energy from drinking water and cost benefit analysis for an entire city. Journal of Water and Climate Change, 4(1), 11-16.

Blokker, E. J. M., Vreeburg, J. H. G. and van Dijk, J. C. (2010). Simulating residential water demand with a stochastic end-use model. Journal of Water Resources Planning and Management, 136(1), 19-26. doi: doi:10.1061/(ASCE)WR.1943-5452.0000002.

ISSO-55. (2013) Tapwaterinstallaties voor woon- en utiliteitsgebouwen, Stichting ISSO, Rotterdam, The Netherlands. 2nd Ed.

Pieterse-Quirijns, E. J., Blokker, E. J. M., Van Der Blom, E., and Vreeburg, J. H. G. (2013). Non-residential water demand model validated with extensive measurements and surveys. Drinking Water Engineering and Science, 6(2), 99-114.

Pieterse-Quirijns, E.J., Blokker, E.J.M., Van der Blom, E. and Vreeburg, J.H.G.: Modelling characteristic values for non-residential water use, Water Distribution System Analysis, WDSA 2010, Tuscon, AZ, USA, 12-15 September, 2010.

Pieterse-Quirijns, E.J. and Van de Roer, M.: Verbruikspatronenbibliotheek, KWR, Nieuwegein, The Netherlands, 2013.

Scheffer, W.J.H.: Het ontwerpen van sanitaire installaties, Misset uitgeverij bv, Arnhem, The Netherlands, 1994 (2e druk).

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

5.1 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.

5.2 Method

Social-technical systems are dynamically stable and are able to resist changes, (§2.2). The MLP described in (Chapter 2) 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 3. Drivers and actors are identified. We characterize these drivers and actors according to the influence-levels as shown in Figure 5. 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.

5.3 Analysign 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 Chapter 2.

5.3.1 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 20). 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.

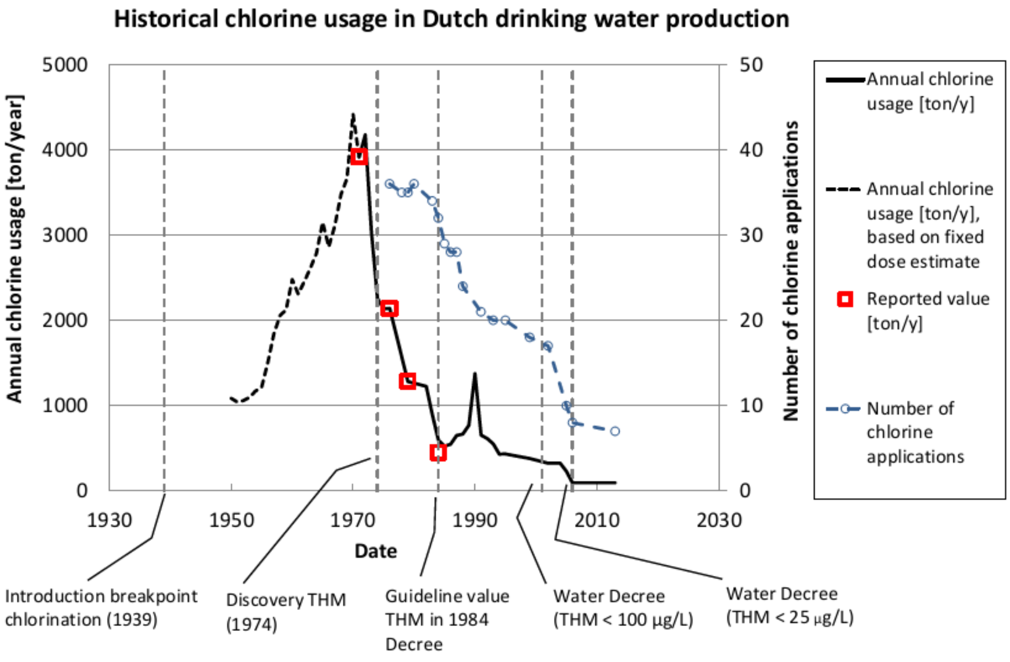


Figure 20 Indication of the historical chlorine usage in Dutch drinking water production for the period between 1950 and present. 'Reported values' (marked ☐) are based on data available from literature. 'Annual chlorine usage' (solid line) is a composed estimation based on different sources. 'Annual 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.

5.3.1.1 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 20 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 en 2005.

Some of the major facility changes (both investments and optimization) are listed inTable 3.

5.3.1.2 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.

5.3.2 Transition characterization

5.3.2.1 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 3 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.

5.3.2.2 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 20, 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, §2.5, as shown in Figure 21. 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.

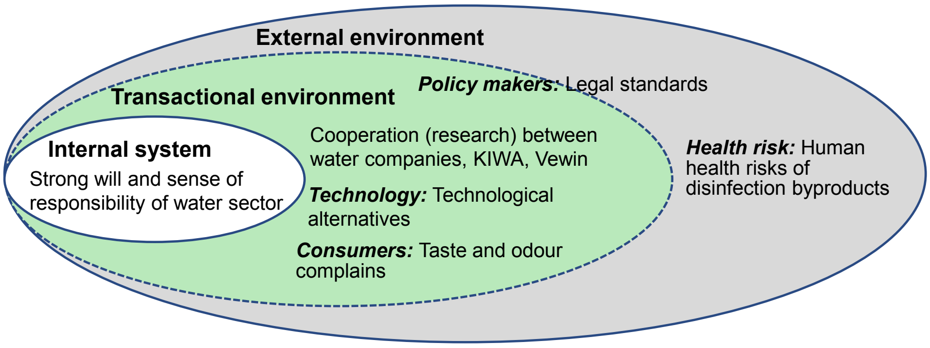


Figure 21 Classification of the drivers of the transition of chlorine usage in drinking water production in The Netherlands according to the three levels of influence model of Gharajedaghi.

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.

5.3.2.3Dynamics 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’.

5.4 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.

5.5 References

Annual reports WRK I/II and WRK III

AWWA, Handbook of Water Quality and Treatment, 3rd Edition, McGraw Hill, 1971

Bellar, T.A., Lichtenberg, J.J., The occurence of organohalides in chlorinated drinking water, JAWWA 66, 1974

CBS website, Grond-opp. Water verbruik: http://www.cbs.nl/en-GB/menu/themas/industrie-energie/publicaties/artikelen/archief/2002/2002-0950-wm.htm

de Moel, P.J., Verberk, J.Q.J.C., van Dijk, J.C., Drinkwater – principes en praktijk, 2004.

Galjaard, G., Martijn, B., Kamp, P., Kruithof, J., Zuiveringsstrategie PWN voor verwijdering organische microverontreinigingen, H2O 41 no. 18, 2008

Geels, F. W., Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study." Research Policy 31, 2002

Jongkind, K., Uitbreiding Zuivering Berenplaat, Evides Waterbedrijf, 2006

Kruithof, J.C., Vorming en verwijdering van trihalomethanen, H2O 13 no. 25, 1980

Kruithof, J.C., Commissie neveneffecten van de chloring, Neveneffecten van de chloring, Kiwa-report (Mededeling 74), 1984

Kuyt, B., van Haren, J., van der Veer, A.J., Engwirda, E., Afschaffing chlooropslag drinkwaterproduktiebedrijf Berenplaat, H2O 18 nr.20, 1985.

Huijts, P.H., Sonneveldt, A., Rapport chloor/chloorbleekloog dosering op het bedrijfsterrein Petrusplaat met mogelijke wijzigingen bij de aanvang van ruwwaterafname door het bedrijf WNWB; Chloorbleekloog dosering pompstation ‘130’ en pompstation ‘Kerksloot’ bij realisering van de chloorbleekloog dosering ter plaatse van het pompstation ‘Kerksloot’, internal report DWL Rotterdam (currently Evides), 1978

IJpelaar, G., Hofman, J., van der Meer, W., Ongewenste stoffen gesignaleerd: verwijderen of omzetten? H2O 38 no. 16, 2005

Lekkerkerker-Teunissen, K., Advanced oxidation and managed aquifer recharge: a synergistic hybrid for otrganic micro-pollutant removal, PhD Thesis Delft, 2012

Lenntech website: http://www.lenntech.nl/

Medema, G.J., Safe distribution of drinking water without disinfectant residual, 2009

Meijers, A.P., Werkgroep ozon, Werking van ozon t.a.v. kleur, smaak en organische stoffen, Kiwa-report (Mededeling 37), 1975

Meijers, A.P., Werkgroep Problematiek van de Haloformen, Problematiek haloformen, Kiwa-report (Mededeling 57), 1978.

Noij, Th.H.M., Noordsij, A., van Genderen, J., Drinkwater uit oppervlaktewater, Kiwa-report (Mededeling 107), 1989

PATO, Postacademische cursus Chemische en fysische waterzuiveringstechnieken, 1985

Rook, J.J., The formation of haloforms during chlorination of natural waters, J. Soc. Wat. Treatm. Exam. 23, 1974

Rook, J.J., Über das Verhalten desinfizierter Wässer in Rohrleitungen, Schriftenreihe des Vereins fuer Wasser-, Boden- und Lufthygiene, 1970

Rook, J.J., Chloor en chloorproducten, H2O 11 no. 2, 1978

Schellart, J.A., De kwaliteit van het Amsterdamse drinkwater voor en na het stoppen van de veiligheidschloring, H2O 23 no. 3, 1990.

Smeets, P.W.M.H., Medema, G.J., van Dijk, J.C., The Dutch secret: how to provide safe drinking water without chlorine in the Netherlands, Drinking Water Engineering and Science, 2009

van der Kooij, D., Lieverloo, J.H.M., Schellart, J.A., Hiemstra, P., Distributing drinking water without disinfectant: highest achievement of height of folly?, J Water SRT – Aqua, Vol 48 no 1, 1999.

van der Kooij, D., Lieverloo, J.H.M., Gale, P., Stanfield, G., Distributing drinking water with low or zero disinfectant residual – operational and biological aspects, Kiwa-report (Mededeling 127) / UK Water industry Research Limited, 2002

van der Kooij, D., Clement, J.A., Rhodes Trussell, R., LeChevallier, M.W., Haas, C., Kuhn, W., The disinfectant residual dilemma, Journal of American Water Works Association, 91(1), 1991.

van Genderen, J., Nevenproducten van chemische desinfectie in drinkwater: een toxicologische beoordeling op basis van literatuur- en praktijkgegevens, Kiwa-report, 1998

van Veldhoven, N., Witte, R., Transportchloring rivierwater verleden tijd, H2O 15, 2002

Vinke, G., De bouwkundige aanpassing van pompstation Andijk, H2O 37 no. 21, 2004

Versteegh, J.F.M., te Biesebeek, J.D., The quality of drinking water in the Netherlands in 2002, RIVM, 2002.

Versteegh, J.F.M., te Biesebeek, J.D. , The quality of drinking water in the Netherlands in 2003, RIVM, 2003.

White, G.C., Handbook of chlorination, Van Nostrand Reinhold Company, 1972

Wijnstra, G., Nieuwe zuiveringstechnieken, 29e vakantiecursus in drinkwatervoorziening, 6 en 7 januari 1977 te Delft, 1978

Acknowledgements

We would like to thank J. Kruithof, W. Oorthuizen, J. Bahlman, D. v.d. Kooij, L. Keltjens, E. Baars, J. Hooft, as well as the KWR colleagues for their contribution and their kind willingness to assist in this research.

6 Raw water transition

6.1 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 chapter 2.

6.2 Method

We have based our research on the phases shown in Figure 3. 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
    a. Getting the transition underway (between predevelopment and take off): the transition's triggers.
    b. 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 §6.3.6.

6.3 Describing the transition

6.3.1 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.

6.3.2 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:

6. 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).

6.3.2.1 Water demand

In 1978, Vewin brought out a ten-year plan which contained a forecast for water demand for the 1978-1990 period, Figure 22. It anticipated that water consumption in the Netherlands would increase from 1 billion to 1.58 billion m^3 per year.

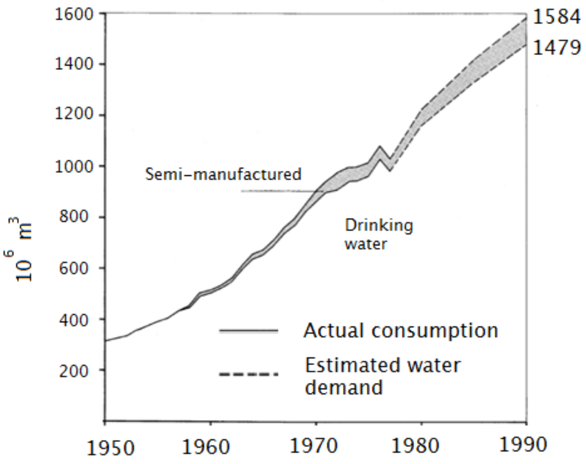


Figure 22 Water consumption 1950 – 1977 and estimated requirements until 1990 (source: Vewin tienjarenplan '78).

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 23 shows that actual drinking water consumption fell far short of the 1978 prognosis.

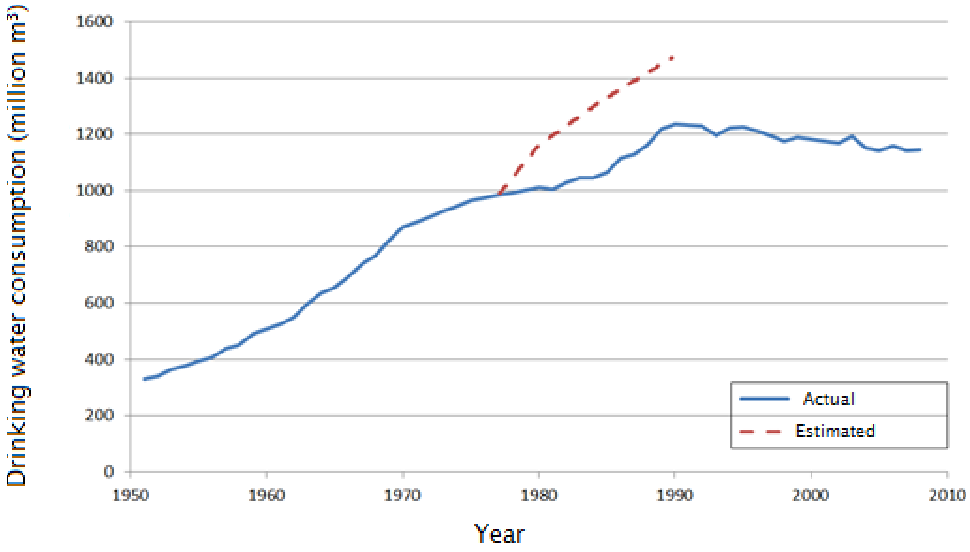


Figure 23 Actual drinking water consumption compared to 1978 forecast.

6.3.2.2 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.

6.3.2.3 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 3.

6.3.2.4Groundwater 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 4 (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 4 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	Agriculture	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 5. 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 5 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

6.3.2.5 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.

6.3.2.6 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.

6.3.2.7 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.

6.3.3 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.

6.3.3.1 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:
    - D) Meuse banks upstream from Samsbeek
    - E) Sand extraction at Beers
- Abstraction of surface water
    - G) Biesbos reservoirs
    - H) 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.

6.3.3.2 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.

6.3.4 Acceleration phase

6.3.4.1 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 6 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 6 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.

6.3.4.2 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.

6.3.5 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.

6.3.5.1 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 24.

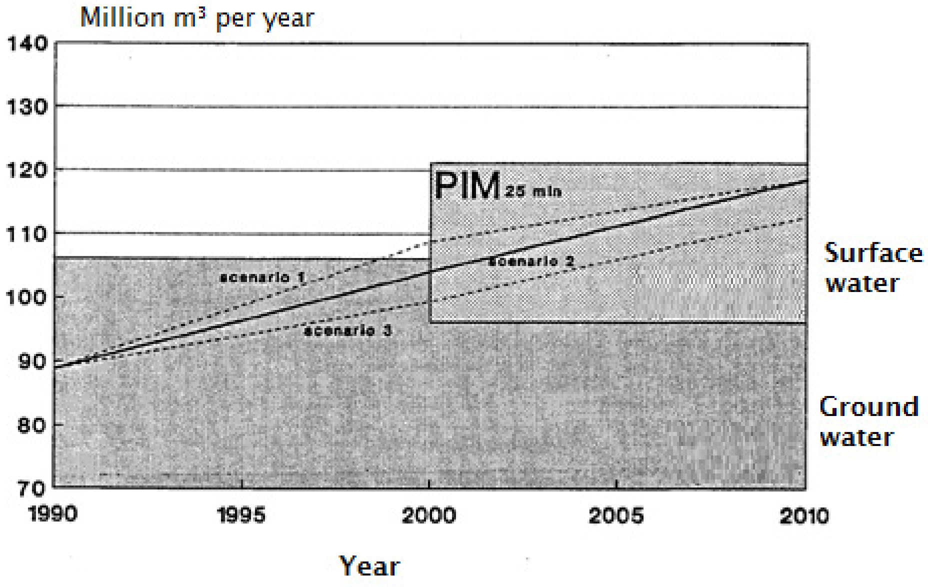


Figure 24 Prognosis of drinking water consumption and maximum licence capacity (source: MER, report part 1).

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 licence 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 25. 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.

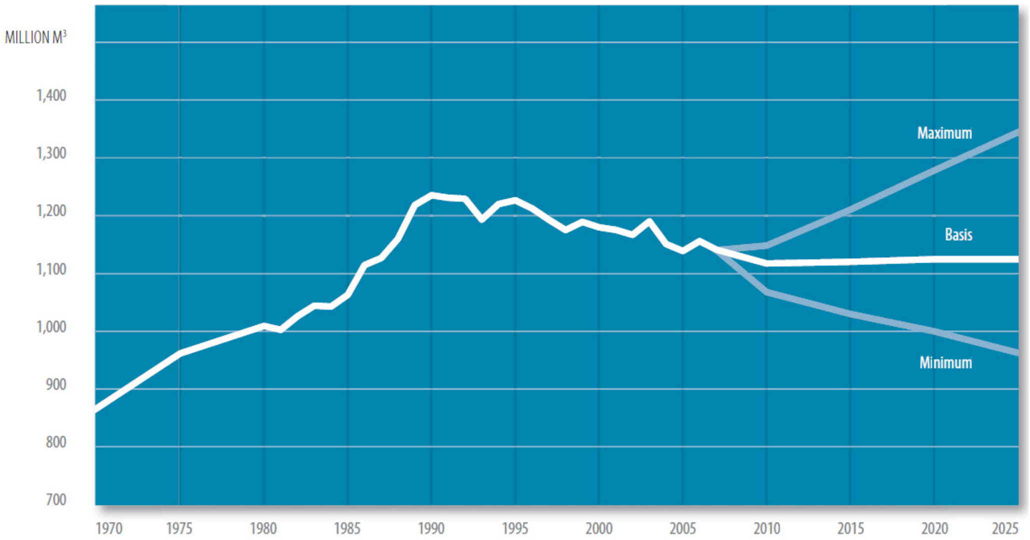


Figure 25 History and prognosis of drinking water demand 1970 – 2025 (source: Vewin Drinking water statistics 2008).

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 m^3/year
- Vessem: 2 million m^3/year
- Empel: 2 million m^3/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.

6.3.5.2 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.

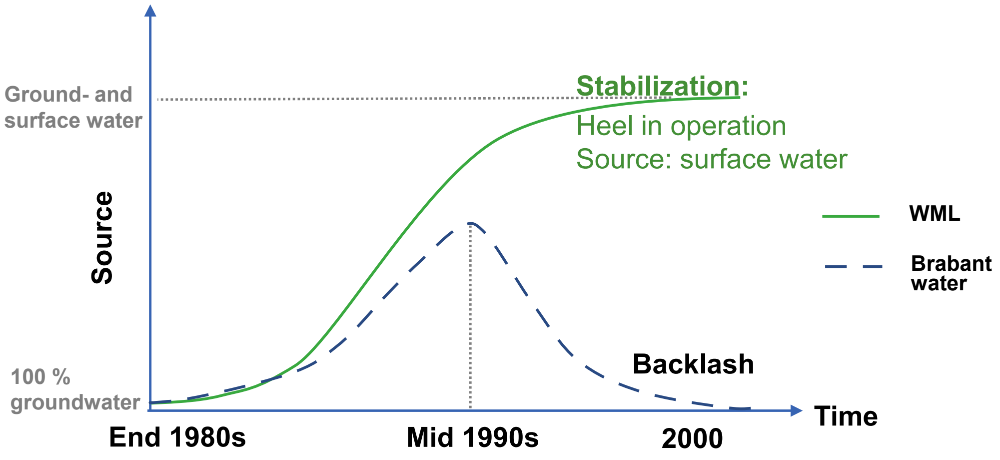


Figure 26 Schematic transition for the two water companies.

6.3.6 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.

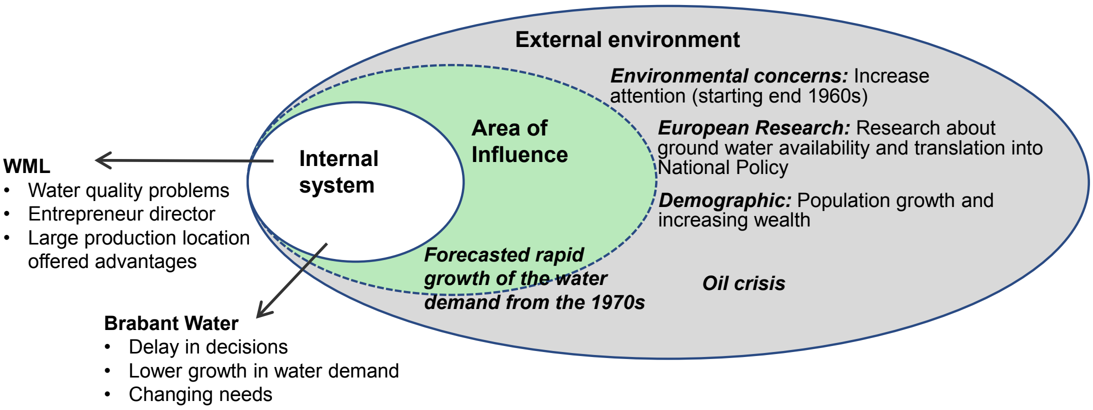


Figure 27 History and prognosis of drinking water demand 1970 – 2025 (source: Vewin Drinking water statistics 2008).

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:
    A) control was kept in-hand
    B) a choice was made that came closest to the preferred source, namely, groundwater
    C) 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.

6.4 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.

6.5 References

Grondwaterplan Provincie Noord-Brabant (1987).

Jelgersma, S., C.R. Meinardi, J.A.M.van der Gun, C.van den Berg, M.A. Damoiseaux, J.J.Fried (1982). Grondwater in Nederland Behoeften en beschikbare hoeveelheden. Commissie van de Europese Gemeenschappen.

Maas C. (1990). Alternatieven voor grondwaterwinning in oost Brabant. Nieuwegein, KIWA SWO 90.230.

Peters, Ir. J.H., ir. J.A.M. Leeuwis-Tolboom, drs A.A. Kooistra en ir. M.J. Schouten. Brede kijk en de zoektocht naar een duurzame set grondwatervergunningen. Fase 1 en 2.

Tweede structuurschema Drink- en industriewatervoorziening (1985)

Verheijden, Ir. S.M.L. (1995). Milieu-effectrapport Project Infiltratie Maaskant. Deelrapport 1: Doel en motivering voorgenomen activiteit. Rapportnummer: SWO 94.363. 's-Hertogenbosch, March 1995.

Vewin (1978). Tienjarenplan ’78. Samenvatting. Rijswijk, June 1978.

Vewin (2001). Waterleidingstatistiek 2001. Rijswijk, November 2002.

Vewin (2012). Drinkwaterstatistieken 2012. De watercyclus van bron tot tap. Vewin nr: 2012/110/6259. Rijswijk, January 2012.

7 Discussion

7.1 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 3) and development of new guidelines (Chapter 4). Additionally, fast growing demand influenced the plans of water companies regarding their water sources (Chapter 6). Also changes occur at water production facilities for instance by adapting new treatment technologies (Chapter 5).

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 7 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 7 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	

7.2 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 7. 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 6. 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.

7.3 Sphere of influence

In the different cases, different (f)actors in the sphere of influence could be identified, Figure 28. 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.

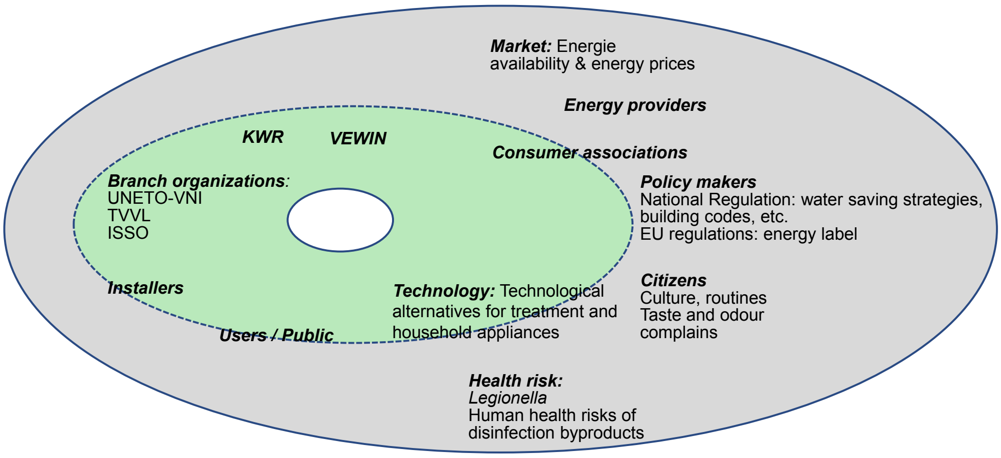


Figure 28 Example of some (f)actors in the sphere of influenced identified in the studied cases.

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).

7.4 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 8 shows different aspects of the drinking water system as a socio-technical system, which were identified in the cases.

Table 8 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.