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Long term planning for the water supply system of the Metropolitan Area of Amsterdam under new water saving regimes of the retail customers

Understanding the system and addressing uncertainties

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Preface – Acknowledgements

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Abstract

Long term planning for the water supply system of the Metropolitan Area of Amsterdam under new water saving regimes of the retail customers - Understanding the system and addressing uncertainties

The centralized drinking water supply system of the Metropolitan Area of Amsterdam, operated and owned mainly by Waternet, has high performance indicators and satisfies the full demand for water in the urban grid and surrounding areas on a full cost recovery basis. Social and technological developments, stemming mainly from (i) the increasing world-wide concern about the sustainability of resources, water scarcity and the effects of climate change, (ii) concepts related to integrated urban water management with a target towards sewage load reduction and rain water retention, and (iii) innovation in housing appliances and waste-water treatment technology, suggest that the current regime of drinking water demand of retail customers could change. A decrease of water demand concerns the water utility, that is operating a system in under-capacity and is currently working on a Long-Term Vision for their water supply system. The future seems highly uncertain and it is essential to understand (i) *how* and *by whom* water saving could be induced in an area of abundant water resources like the Metropolitan Area of Amsterdam and (ii) what kind of effects a further decrease of water demand could bring about. Standard Policy Analysis techniques are applied to address this issue and the approach is largely qualitative. Desk study and interviews are conducted to collect information and data that are systemized and further processed through uncertainty and systems analysis to supply an answer to the above. The anticipated changes that could lead to water saving –*drivers of water saving*– are clustered in categories for supplying clarity and are, then, classified according to their potential effect and uncertainty. Stakeholders and their actions that could induce water saving are also identified. The system is decomposed into embedded subsystems in order to identify potential effects on each one, and mitigating alternatives are discussed after examining the available practices for maintaining a high performing water supply system. The analysis supplies insights on the type of information that Waternet needs to seek in order to perform educated explorations about the future, as well as on how this could be achieved. The outcome of the research can be utilized towards this end and towards developing further the Long-Term Vision of the water supply system. However, further research is necessary in order to make elaborate quantitative estimations in this direction.

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Chapter 1. Introduction

This chapter supplies an overview of the problem, the context and the relevance of the study.

Waternet, the publicly owned utility responsible for water supply in the Metropolitan Area of Amsterdam, is maintaining a system of high level of performance, characterized by a trend of decrease in the water demand (see also Chapter 4) and a *full cost recovery* regime. The water utility supplies drinking water to retail customers through its distribution system. At the same time, they sell drinking water to wholesale customers and water of a second quality to industrial customers. The future of water demand seems highly uncertain, as emerging concepts and technologies, regarding more *water aware* buildings, suggest a potential (further) decrease in the demand of the retail customers. Currently working on a long-term vision for the water supply system, Waternet is concerned with this possibility and the potential impacts to their well performing system, as the adaptivity of the system to decreased water demand has not yet been investigated.

Where do these concerns regarding drinking water demand decrease in the Metropolitan Area of Amsterdam stem from? Global issues related to and/or affecting water, such as the climate change, draught events, regional water unavailability and increasing urbanization, have risen an interest for a more sustainable water use. UNESCO considers water (un)availability an issue for which informative campaigns are essential globally; they suggest conducting global discussions in decision making level that should include Europe (UNESCO, 2013). The World Water Council also recognizes the importance of raising awareness to drinking water issues and including decision makers in the discussions (World Water Council, n.d.). The United Kingdom, Italy, Spain, Portugal and Australia, characterized by water shortage, are some of the countries whose governments "have started to consider buildings as a means to tackle water scarcity", with the United Kingdom being "the most advanced and ambitious example in the EU" (Mudgal et al., 2009, p. 6). At European Union level, the European Commission has been promoting the idea of consuming less drinking water in buildings, for example by including the monitoring of water usage and the decrease of water consumption in the Community Eco-labels for buildings (*Establishing the ecological criteria for the award of the Community Eco-label for Buildings*, n.d.). At the same time, the National Government of the Netherlands stresses the attention to the potential environmental problems caused by extracting large quantities of water for satisfying demand (Rijksoverheid, 2013a). It becomes clear that water is increasingly viewed as a natural resource that should be used sparingly only when and where needed. Better water performance of buildings is included in contemporary debates and is sometimes part of the political agenda. At the same time, new concepts and technologies have been developed that attempt to promote and apply the above. A few examples of the former are the Integrated Urban Water Management (IUWM) and the Water Sensitive Urban Design (WSUD) (Cook et al., 2009), as well as the Sustainable Urban Water Cycle (SWC) (Van Leeuwen et al., 2011) and the "Interconnecting Water" vision (Fokké et al., 2009, n.d.) which have been discussed in the Netherlands. Technological improvements and innovations that can lead to water saving vary, ranging from low-flush taps (*Establishing the ecological criteria for the award of the Community Eco-label for Buildings*, n.d.) to washing machines that could use ozone and dishwashers that could use steam (Fokké et al., n.d.), and from rainwater harvesting systems (*Establishing the ecological criteria for the award of the Community Eco-label for Buildings*, n.d.) to small-scale water treatment technologies that enable recovery of materials and water reuse (*Annual Report of the Section of Sanitary Engineering*, 2011). A lot of discussions about water use take place globally, whereas new concepts and technologies are becoming increasingly available. Ranging from published news and political action to specialized scientific research and promotion of innovative technologies, the above supply the complex and rather chaotic context of Waternet's concerns about a potential drop in the water demand. It is hard to foresee how these developments will affect the water demand at the Metropolitan Area of Amsterdam.

The multiactor environment of the problem in hand should not be neglected. Complexity is increased as a large number of stakeholders interact and make decisions that could affect water consumption. Think of a householder that buys water efficient equipment, a supplier that only trades water aware appliances or a regulator who enacts relevant legislation. Understanding who the critical stakeholders are is essential not only for the present but also for the future. Monitoring their actions, identifying their long-term strategies and/or communicating with them can repeatedly supply additional insight and facilitate long-term planning for the water supply system. Focusing solely on the physical system would limit the available ways to tackle this problem.

Policy Analysis techniques are helpful when a complex situation needs to be clarified. From defining the problem and understanding its potential multiactor dimension to dealing with uncertainty and attempting to explore the future (Enserink et al., 2010; De Haan and De Heer, 2012), simple qualitative approaches can prove more beneficial than elaborate and specialized quantitative models – even though the latter can form very useful tools once understanding has been established. In this thesis research, standard Policy Analysis techniques have been utilized in an attempt to systemize and structure a wide range of available knowledge and information from several fields into useful products for Waternet (see also Chapter 2). The latter should help the company plan their next steps towards formulating the long-term vision of the water supply system. Techniques have been critically applied to maintain a focus on *water saving* and avoid generalized analyses that would not supply additional insight to the problem owner.

Taking into consideration the above and analysing the objectives of the problem owner, the main dilemma arises:

> *How to maintain a good performing water supply system in an uncertain environment while maintaining low costs?*

Waternet needs a robust long-term planning strategy that could offer adaptivity in terms of the uncertainties that lie ahead. However, the situation as described above is chaotic and not yet fully understood. Thus, the problem cannot be addressed as is. The drivers of water saving in an area of abundant fresh water resources, such as Amsterdam, need to be clarified. At the same time, the potential effects of lower water consumption to the performance of the system need to be identified. An *investigation of the uncertainties and* *knowledge gaps* that characterize this problem is essential. Once these are understood, Waternet will have a new insight on how to plan into the future.

The latter is the contribution of the thesis research to the long term planning of the water supply system: by structuring abundant information and fragmented knowledge, a new understanding of the situation and the system is realized. On one hand, drivers of water saving are identified and classified according to their uncertainty and expected impact. This enables Waternet to build educated future scenarios for the water demand based on localized information and not solely on traditional water demand forecasting methods. Understanding *who* has the knowledge that the company needs and *who* can affect water demand is crucial for this. Realizing that future uncertainty cannot be eliminated is also significant: constant monitoring of developments is important (see also Chapter 6). On the other hand, the effects of water demand reduction on the system are investigated qualitatively through a system decomposition and a conceptual systems analysis of the subsystems. It is revealed that, to a certain extent, there is no readily available knowledge to estimate the system's response to such changes. There are ways to maintain the good performance, however these may come at a cost that cannot yet be quantified. The above are explored with the focus on a potential water demand reduction by the retail customers – the suggestion of the problem owner was adopted after exploring whether, indeed, this would be the most beneficial focus of the research (see Chapter 4). The water supply system is explored to its whole, from source to distribution, whereas in-building water installations are also briefly discussed. Information and data was gathered through desk research and interviews (see also §1.2).

1.1. Research questions

Elaborating on the above brief description of the situation and the complication of the issue, the main research question of this study is:

> *What are the uncertainties and knowledge gaps regarding a decrease of water demand in the Metropolitan Area of Amsterdam in terms of (i) drivers of water saving by retail consumers and (ii) the effects of decreased water demand to the water supply system, and how could these uncertainties and knowledge gaps be addressed?*

The main research question is investigated through the following 4 sub-questions, each of which is elaborated further.

Q1. How is the water supply system functioning?

- Q1.a. What is the technical system like?
- Q1.b. What is the current consumption trend, which are the sale types and who are the customers?
- Q1.c. What is the current long term vision and planning for the water supply system?
- Q1.d. What would be a suitable way to decompose the water supply system into embedded subsystems in order to identify the potential effects of retail consumption drop?

Q1.e. How could the subsystems be conceptualized in terms of input and output information for planning and operations?

Q2. Which are the drivers of water saving, which are the main relevant stakeholders and which areas are more prone to such changes?

Q2.a. Which are the dynamics of change and renovation in an urban environment and which stakeholders are responsible for each of these?

Q2.b. Which are the main types of change in the water consumption regime that could cause water saving and which are their main drivers?

Q2.c. Which drivers of water saving have the highest impact and the highest uncertainty for the Metropolitan Area of Amsterdam?

Q2.d. Which actors could promote or adopt water saving, generating a significant impact, and how could they do this?

Q2.e. Could one pin-point areas that are more prone to water demand reduction, i.e. where water saving could be more intense or more unexpected than others?

Q3. How could the performance of the water supply system be affected by a drop in demand and how could the adverse effects be mitigated?

Q3.a. Which are the main objectives and performance indicators of water supply systems and how are their values estimated?

Q3.b. Which are the design elements and the main operational rules to achieve high levels of performance?

Q3.c. Which performance indicators and, hence, objectives of the water supply system could be affected by a drop in demand and how?

Q3.d. Are there areas that are more prone to these effects than others?

Q3.e. What alternatives are there to mitigate the adverse effects and what are, in turn, the expected impacts of each alternative?

Q4. How could Waternet use the knowledge acquired from the above research to address future challenges?

The answers to the questions are supplied throughout the report, however a more targeted answer is supplied in the concluding chapter. For the interested reader, a detailed table that indicates the location of the answers per sub-question is supplied in the Appendix (see Table A - 1 of the Appendix of Chapter 1).

1.2.Approach

The water supply system is addressed and analyzed to its whole, from source to consumption, based on information and data that was collected through desk study and interviews. The latter are synthesized through conceptual systems analysis and conceptual uncertainty analysis. The approach is qualitative due to time constrains, however a few quantitative figures that are essential for understanding the current system have been included in the report. An example is given of how a quantitative approach could supplement the analysis.

The desk study concerned (i) internal documentation of Waternet, (ii) published articles in scientific journals, (iii) publications by research institutions regarding ongoing research and technological developments in wastewater treatment, (iv) publications by domestic installation suppliers regarding the installation, operation and maintenance of rainwater harvesting and greywater recycling systems, and (v) extended online research on sustainability pilot projects in the Netherlands and abroad, urban water demand management programs and water saving recommendations by governmental and other parties, targeted directly to citizens. Understanding of the above has helped demarcate a systemization that could clarify where changes in water demand could stem from and what kind of effects they could bring about to the water supply system. In other words, the extensive literature has facilitated the categorization of the drivers of water saving (see Table 6 in Chapter 3) and the identification of potential effects by reduced water demand (discussed in Chapter 3 and summarized in §5.3, Table 13).

A total of 19 interviews were conducted with 18 people, excluding a small number of meetings that helped delineate and conclude the research. Several of the interviews were conducted with two interviewees simultaneously, whereas some persons where interviewed more than once. The list of interviewees consists of 17 employees of Waternet at different levels of management and operation (one of the interviewees is also a professor at the Delft University of Technology and another one is also working for VEWIN, the Association of Dutch Drinking Water Companies) and 1 employee at management position at the Fire Department of Amsterdam-Amstelland. More details on the position(s) of each of the 18 interviewees are included in Table 1.

The main purpose of the interviews within Waternet was to become familiar with the case study in terms of the water supply system's structure, functions, operations and objectives. A secondary goal has been to identify the objectives of Waternet as a whole, in order to ensure that the problem is delineated and the recommendations are formulated according to the organization's interests and needs. A third aim was to gain an understanding of what the employees of Waternet have experienced or are expecting in terms of water demand and water saving in the Metropolitan Area of Amsterdam. The interview at the Fire Department aimed at gaining insights on the possibilities of removing fire hydrants from the distribution system. Last but not least, a general goal of all interviews has been to identify data and knowledge that is already available (or accessible) to Waternet, and which, after elaboration, could prove useful in addressing future uncertainties.

The interviewees that could supply useful information for the research were indicated by colleagues within Waternet and the interviews were conducted mostly through open questions. As knowledge gaps were identified along the research, new interviewees were sought for; the external supervisor of the thesis, the colleagues at the Strategic Centre and the interviewees themselves indicated which persons could supply (further) useful insights. A brief description of the content of the interview was sent in advance. By this introduction, the interviewee was able to prepare. In several cases, the interviewees had brought along relevant documentation or had asked one more colleague to attend the meeting and give their own insights. In an effort to understand a large and complex system, occasionally the discussion would gain a different direction than expected at the beginning. When this deviation from the planned interview seemed insightful, the interviewee was encouraged to continue in the new direction. Information collected through interviews and internal documentation was validated in subsequent meetings; this proved necessary when the initial source was not clarified or when data was contradicting. Ensuring that information was accurate and up-to-date was a basic reason of conducting more than one interviews with certain colleagues, as well as of seeking additional contact when necessary.

TABLE 1 LIST OF THE POSITION OF THE INTERVIEWEES

#	Organization	Position	Sector (within Waternet)
1	*Waternet*	Executive Officer	Strategic Centre
2,3	*Waternet*	Strategic Advisor	Strategic Centre
4	*Waternet*	Team Leader Policy Support	Drinking Water
5	*Waternet*	Senior Asset Manager (Distribution)	Drinking Water
6,7,8	*Waternet*	Asset Manager	Drinking Water
9	*Waternet*	Advisor	Drinking Water
10	*Waternet*	Distribution Engineer (Hydraulic Modelling)	Drinking Water
11	*Waternet*	Services Marketeer	Customer, Market & Relations
12	*Waternet*	Key Account Manager	Customer, Market & Relations
13	*Waternet*	Data Analyst	Customer, Market & Relations
14	*Waternet*	Environmental Technology Advisor	Research & Projects
15	*Waternet*	Researcher	Research & Projects
16	*Waternet*	Senior Advisor Legal Affairs	Resources
17	*Waternet*	Advisor Legal Affairs	Resources
(1)	*Delft University of Technology*	Chair on Drinking Water Engineering	N/A
(9)	*Association of Drinking Water Companies (VEWIN)*	Member Delta program Freshwater	N/A
18	*Fire department of Amsterdam-Amstelland*	Team Leader Accessibility, Fire-fighting Water Provisions & Attack Plans	N/A

The collected raw data and information have been processed and elaborated into other types of products. Unless stated otherwise, all tables and figures of this report are genuine products of combining information of at least two sources. It has been a challenging task to make a synthesis of abundant and detailed information into more abstract and targeted products fitting the focus of the research.

As already discussed, Policy Analysis techniques have been applied to systemize and clarify the knowledge acquired throughout the research. The theoretical context and justification of the chosen methodologies are discussed in Chapter 2. The uncertainties in terms of future water saving are firstly analyzed through identifying the drivers of water saving (financial/regulatory, social and technological) and ranking them according to their uncertainty and impact. As a second step, the stakeholders that can introduce or adopt water saving drivers and generate a significant impact are also identified. Their actions that can induce water saving are presented and ranked according to their uncertainty. In terms of the effects of potential water saving, firstly, the water supply system is analyzed through an *input-output* conceptual system diagram. This diagram is generic and is valid also for the system of Waternet. The aim is to indicate the main inputs for the design and operations of water supply systems, as well as the monitored output which supplies data for the assessment of system performance. Through this conceptualization, the familiar reader is supplied with an overview of the main system functions, both technical and managerial, whereas the unfamiliar reader gains a first targeted understanding. Then, the water supply system of the Metropolitan Area of Amsterdam is decomposed into embedded subsystems that are conceptualized, further, through input-output diagrams. The decomposition aims at understanding that the design of the system is characterized not only by *propagation* of characteristics, but also by *blocked propagation*. Thus, not only the subsystems, but also the linkages between the subsystems are presented. This conceptual system decomposition and analysis forms the tool to identify the effects of water saving and the technical mitigating alternatives.

1.3.Guide to the reader

Chapter 2 supplies an overview of the scientific relevance of the research with a focus on ways to address uncertainties in long-term planning of infrastructure.

Chapter 3 serves as a condense source of information about water supply systems and water demand regimes. The architecture of water supply systems in terms of technical design and operations are presented, as well as typical water consumption regimes and possible water saving drivers. This Chapter is generic and applicable to any urban water supply system, however the presentation is such to fit the rest of the analysis. The reader who is familiar with water supply systems is advised to specifically read the introduction of Chapter 3 and the 3rd paragraph (3.3).

Chapter 4 gives an overview of the water supply system of the Metropolitan Area of Amsterdam. Readers who are familiar with the system are advised to focus on the 2nd and the 3rd paragraphs (4.2, 4.3).

Chapter 5 contains the core analysis of the study. It includes the classification of water saving drivers in terms of their uncertainty and impact, the actions of relevant stakeholders that can affect water consumption, the potential effects of water demand reduction to the system and the mitigating technical alternatives.

In Chapter 6 conclusions and recommendations are discussed. Additionally, a reflection on the research project and the chosen methodology is included.

Chapter 2. Planning the future of complex water supply systems under uncertainty

This chapter discusses the analysis that is conducted in the present thesis by referring to state of the art publications in the area of policy analysis and systems analysis.

Uncertainty stems from the uncontrollable factors of a situation, thus it is important to identify both the drives of change and the possible effects to the system of interest. It is also significant to acknowledge that (i) in a multi-stakeholder environment the actions of others may generate changes, and that (ii) in a complex system not only the effects on the final output, but also the effects on intermediate outputs are of interest.

What lies ahead is in principle unknown to human beings, thus any type of planning into the future can never be certain. Particularly when planning for infrastructures, that are characterized by "long-term logic, management and structure" (Frantzeskaki and Loorbach, 2010, p. 1293), unpredictability tends to augment as is indicated in the widely cited "trumpet of uncertainty" of Rosehead (1990) (see Figure 1).

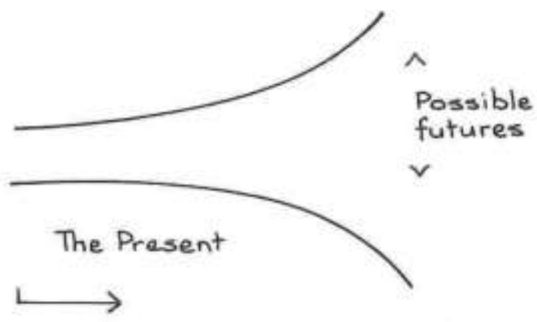

FIGURE 1 THE TRUMPET OF UNCERTAINTY (ROSENHEAD, 1990, P. 195)

"Uncertainties can be the result of a lack of knowledge and may thus be reduced, but they can also be caused by the variability of the system, and so the structural and irreducible nature" (Loorbach and Rotmans, 2006, p. 202). It becomes clear that the investigation of uncertainties should be done under two scopes: (i) missing knowledge and (ii) fluctuation of the variables that may affect the outcomes of interest. The latter involves additional uncertainty: how can one be sure which elements will generate an impact in the future?

Decision making with a long-term scope is challenging and the high investment costs of centralized water supply systems do not allow for sole short-term planning. Decision making in the present needs to take into account the variability of the future environment to ensure reliability and high performance. As Walker et al. (2013) point out, uncertainties should not be ignored:

> *[I]t is important for policy analysts and policymakers to accept, understand and manage uncertainty, since:*
>
> - *given the lack of crystal balls, uncertainties about the future cannot be eliminated;*

- *ignoring uncertainty can result in poor policies, missed chances and opportunities, and lead to inefficient use of resources; and*
- *ignoring uncertainty could mean that we limit our ability to take corrective action in the future and end up in situations that could have been avoided.* (P. 219)

The factors that the problem owner cannot control are in essence the source of future uncertainty; in Policy Analysis these factors are often referred to as the *external* factors of a situation, problem or system (De Haan and De Heer, 2012). The external, or else *contextual* environment, is affected by *driving forces* of change (Enserink et al., 2010). The examination of the driving forces of change and of their effects to the system output, allows for the formulation of strategies and tactics to deal with a given situation (see Figure 2). Measures may aim at controlling the driving forces, changing the system structure or attempting to mitigate the effects themselves (Meijer and Ruijgh-van der Ploeg, 2001).

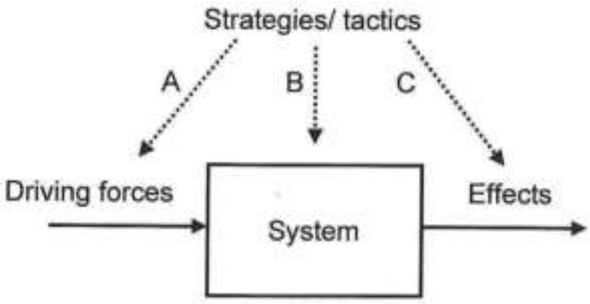

FIGURE 2 STRATEGIES & TACTICS TO DEAL WITH CHANGE AIMING AT THE DRIVING FORCES, THE SYSTEM ARCHITECTURE OR THE EFFECTS (MEIJER AND RUIJGH-VAN DER PLOEG, 2001, P. 169)

A common way to explore the future is to formulate *contextual scenarios* by identifying the driving forces mentioned above and by classifying them according to their uncertainty (high-low) and expected impact to the outcomes of interest (high-low) (Enserink et al., 2010). Typically, the driving forces of high impact and high uncertainty are taken into account in this process (Enserink et al., 2010). However, all factors that can have a high impact, whether *fairly certain* or uncertain, should be included in a problem analysis (De Haan and De Heer, 2012; Walker et al., 2013). These drivers of change are often categorized into the *STEEP factors*, namely factors stemming for the Society, Technology, Economy, Environment and Politics (Bradfield et al., 2005; Bernhard, 2011), an approach which was suggested by Schwartz (1992) without including, then, the environmental aspect. In complex problems, systemization of the multiple driving forces facilitates understanding of the sources of change.

To illustrate the above in the context of the thesis research, the driving forces that are investigated concern *changes of the water consumption* by retail customers. The uncertainty in terms of a decreased future water demand has been identified by the problem owner as the principle concern. Thus, the interest lies in identifying and classifying driving forces of water demand reduction. This process could be perceived as an analysis that aims to provide insight on a problem that seems to have not yet been investigated in the academia, or as a pre-step for scenario formulation. The latter can facilitate the explorative assessment of the future performance of alternative solutions for a problem (De Haan and De Heer, 2012). In more general terms, through scenario formulation one can "reflect on the implications of [plausible] futures on […] infrastructure" (Enserink et al., 2010, p. 137).

Urban water supply systems are situated in urban and housing environments, characterized by multiple actors and social complexity (Bell, 2012; Byrne, 2012). The future of such systems depends largely on stakeholders that act in a broad environment of a water supply system, such as "urban planners, designers, engineers, politicians, managers and planners" (Bell, 2012, p. 55). The stakeholder environment is also characterized by a large number of consumers whose future behaviour and decisions will determine aggregate water consumption. Operating in a multi-actor environment is characterized by diversity of views and ambiguity in perceiving a situation, as well as a differentiation in ways to assess system outcomes (Brugnach et al., 2010; Pahl-Wostl et al., 2010). Not only has each stakeholder goals that can be contradicting to the goals of the problem owner, but it is also highly doubtful whether the actors will agree that there is indeed a problem that needs to be addressed (Enserink et al., 2010).

It becomes apparent that some type of analysis of how actors could operate in the future is vital. An overview of actor analysis methods is supplied by Hermans and Thissen (2009). Even though their study is targeted to *public policy making* and not *decision making* in general, a multiplicity of methodologies for both fields is apparent. Roughly, one could say that methodologies aim at identifying the relations, power structures and potential strategies of the actors that can influence a decision making process or have an impact on the desired outcomes of a decision.

In the present thesis research, the focus lies solely on the decline of water consumption by retail consumers. Even though more stakeholders than the actual consumers are involved in this process, reducing water consumption seems to be primarily a side-effect of their activities. In most cases, the key interests of stakeholders are not directly relevant. To illustrate with an example, the main interest of an appliance supplier is profitability, regardless of the nature of the appliances they trade. In search of this goal, only the sale of water efficient appliances is relevant to the study. Thus, only *particular actions* towards the generic interest are relevant and not an analysis of the interests themselves. For that reason, the implementation of a full actor analysis research was considered redundant at this stage. Stakeholder actions that could affect water consumption are investigated through elaborating on the equivalent drivers: *which actors*, and *through which actions*, could affect each drivers and, hence, future water consumption?

Complexity in water supply systems does not stem solely from their environment. The architecture of the system itself is complex, made up of numerous engineering components and operational practices. Investigating water related problems by decomposing the relevant natural and engineering systems is common, as it facilitates computations (Haimes, 1977). Water systems are thought of as *large-scale complex systems* that are typically decomposed into interconnected subsystems in order to be controlled and operated in an easier way (Filip and Leiviskä, 2009). Decomposition is appropriate when inter-component linkages are thought to be weaker than the intra-component linkages, however not negligible (Simon, 1962).

In this thesis a conceptual decomposition is conducted to the engineering system. The water supply system is decomposed into embedded subsystems, each of which is characterized by several inputs and measurable outputs that allow its monitoring and performance assessment. Systems analysis is conducted with a focus on the system architecture in terms of technical design and operations, at an aggregate level.

Chapter 3. The system architecture of water supply systems, the variability of demand and the incentives of water saving

This chapter serves a triple purpose: (i) supply the basic principles of water supply system design and operation, (ii) discuss the inherent variable nature of water demand in time and space, and (iii) present the main mechanisms and drivers of water saving.

A typical water supply system is presented in Figure 3. Water is abstracted from an available source and treated as needed to reach the desired levels of quality. It is then distributed through a network of underground pipes. Throughout the system and depending on local conditions, such as distance of the source and elevation differences, transport and temporary storage are also common. At the point of sale, consumers may or may not meter the volume of the water consumed. Thus, water invoicing by the drinking water supply company can be based on different criteria for different customers.

FIGURE 3 EXAMPLE HORIZONTAL CHAIN OF WATER SUPPLY IN AN INDUSTRIALIZED COUNTRY

Understanding the objectives of a water supply system is imperative in order to (i) understand its design and operations and (ii) assess, later, the impacts of water demand drop to the objectives, or the *performance*, of the system. The core objective of a drinking water supply system is to deliver constantly good quality of water at a low price. Additionally, it is important to maintain high customer satisfaction and high level of safety. The latter does not only signify that water quality should be high. Accidents that may affect activities in the vicinity of water infrastructure are not desirable; for example the burst of a pipe can cause disturbance to traffic and other social activities.

In Table 2 the multiple objectives of a water supply system are systemized and clustered in categories. One could say that the objectives of water supply systems are largely common, thus only a small number of sources has been utilized to build this table (American Society of Civil Engineers, 1998; Waternet, 2012; "Water and us - Working with water," 2013). The target values and the operationalization of each lower level objective may be defined by regulation or decided upon by the water utility.

TABLE 2 MAIN OBJECTIVES AND LOW LEVEL OBJECTIVES OF A DRINKING WATER SUPPLY SYSTEM

High drinking water quality	High quality of service	Good financial balance	High level of safety
• (Degree of compliance to) health standards • (Degree of compliance to) aesthetic standards	• Continuity of supply • Sufficient pressure • Customer satisfaction	• Operating costs • Capital costs • Income	• (Degree of compliance to) water quality health standards • Level of distrurbance to other activities

Monitoring the performance of water supply systems is not always straightforward; due to financial and practical reasons monitoring is neither constant nor catholic, i.e. there are limitations in time and in space. Measurements are often only indications of the real condition of the system and simulation tends to be the primary tool of assessing system condition. This is the case particularly for the hydraulically complex distribution system. Even more, simulation models entail uncertainties. The exact mechanisms and transformations taking place along the water supply chain are not fully understood, even though the observation has been made that as *residence time* increases, quality degrades (Husband and Boxall, 2011; Furnass et al., 2013). There are also constrains in assessing the condition of pipes. A failure incident (such as a pipe burst or a brown water event) is sometimes the most profound piece of evidence that other parts of the system may, also, not be performing as speculated.

The measurements and recorded data are used as *operationalized criteria* for assessing the level of satisfaction of each objective. Each objective is characterized by multiple criteria, often of different nature. For example, the quality of the water in the distribution system can be assessed both through sample measurements and through records of customer complaints. Additionally, an operationalized criterion may be used for assessing the level of satisfaction of more than one objectives. For example, customer complaints in terms of water quality contribute to the assessment of both water quality and customer satisfaction. More operationalized criteria per objective have been included in the Appendix for the interested reader (see Table A - 2).

The design and operation of water supply systems ensures that objectives are satisfied. The anticipation of water consumption defines the capacity of the system (design) and the rate of production and delivery (operation). Thus, *future water demand estimations* are necessary for both. In detail, long-term forecasting is essential for the design and planning of a water supply system, whilst short-term forecasting is required from operational and managerial purposes (Carragher et al., 2012). Monitored output, such as the actual water consumption or water quality measurements, can serve as feedback information for adjusting operations in a short term manner or operational rules in a more long term manner. Obviously, adjusting the technical design is harder as most system components, such as treatment tanks and distribution pipes, are characterized by high investment costs and long payback periods. However, when one examines the system in a long-term manner, redesign is not out of the question (Frantzeskaki and Loorbach, 2010). A schematic illustration is supplied in Figure 4.

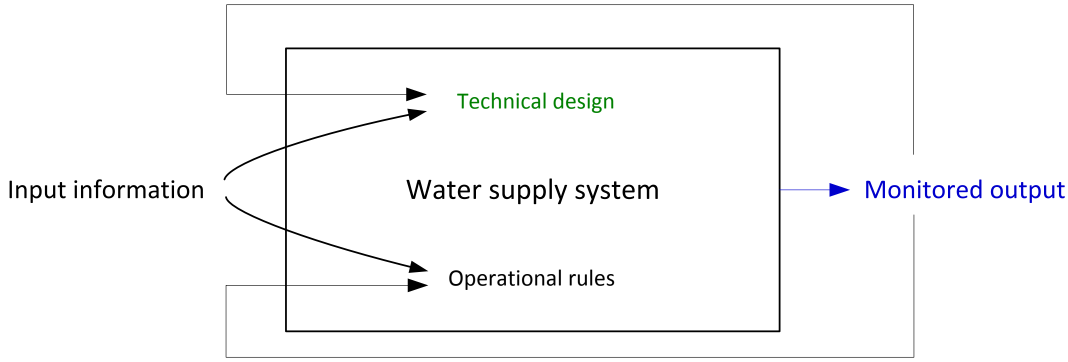

FIGURE 4 SCHEMATIC REPRESENTATION OF INPUT, OUTPUT AND LONG-TERM INFORMATION FEEDBACK LOOP IN A WATER SUPPLY SYSTEM

Figure 5 supplies a more elaborate scheme on the water supply system boundaries and architecture. A simple input-output diagram has been constructed that conceptualizes the main information inputs for the design and operation of a water supply system, as well as the main monitored outputs.

To elaborate on Figure 5, the architecture of an existing water supply system in terms of design and operation is based on information that is constantly changing or is specified in a short-term manner. The long-term technical design is conceptualized on the diagram through the *system capacity* and the *treatment efficiency*, whereas the operations are conceptualized through the *operational rules (including asset management decisions)*. One of the main inputs for both the design and the operations is the forecasted value of the demand. There are multiple *water demand forecasting* methods and they are based on data about past and current consumption regimes (Herrera et al., 2010; Carragher et al., 2012). A regime that was previously observed is generally expected to continue, as traditional demand forecasting methods do not entail *trend breaks*. The *actual water consumption* is a variable factor that describes the technical system, thus located within the boundaries of the water supply system in this generic representation. Operational rules and protocols are dictated by a number of factors, such as scientific knowledge, experience, regulation and deviated local characteristics and measurements. The condition of the system is defined by the technical design, the operational rules and the actual water consumption (both momentary and aggregate). As already mentioned, however, the *real* condition of the system is not known; all available information is restricted to the monitored output.

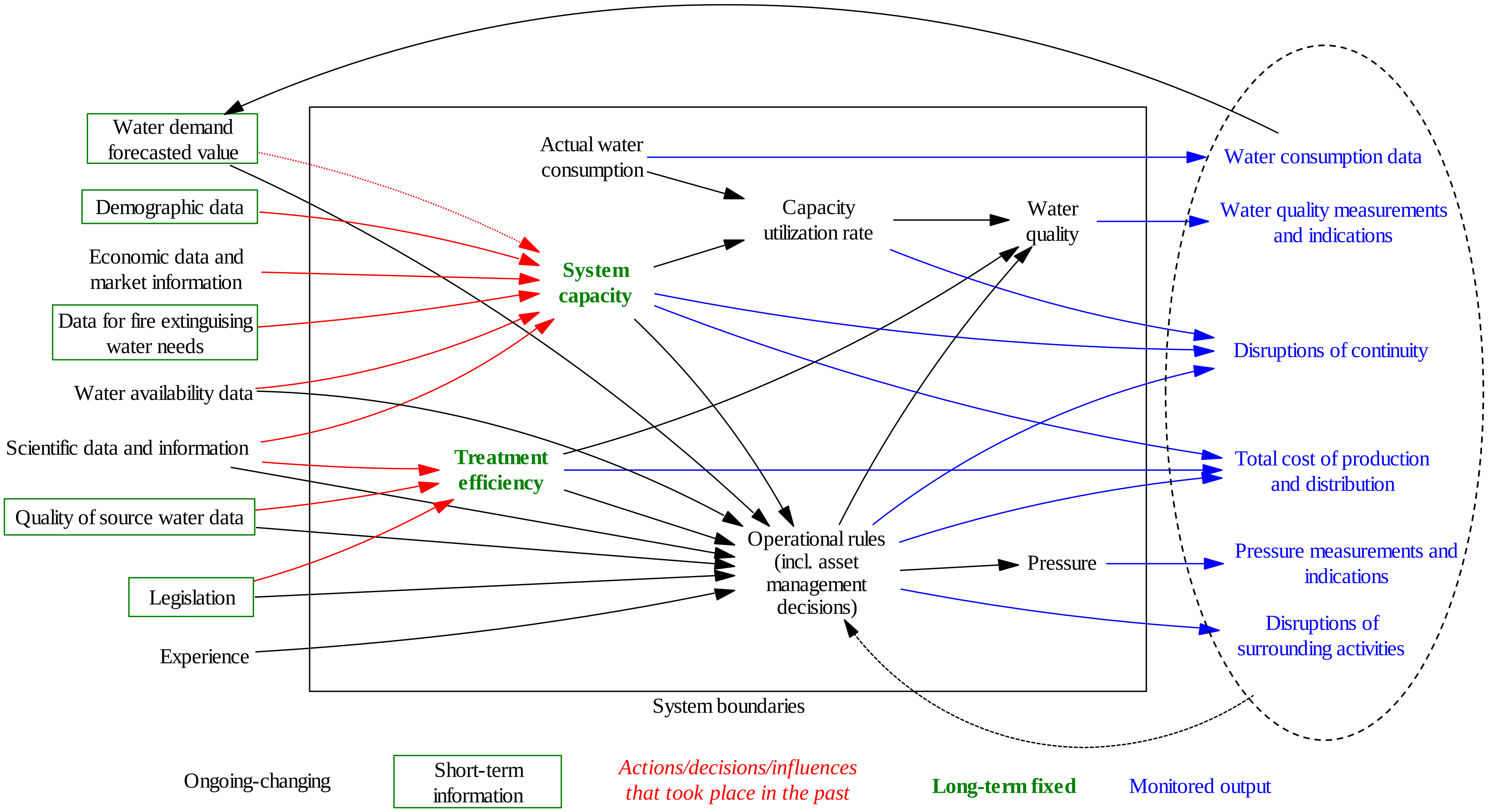

FIGURE 5 DESIGN AND OPERATIONS OF A WATER SUPPLY SYSTEM: INPUTS AND MONITORED OUTPUTS

System demand in an urban environment is often presented through figures of the *number of residents* and the *average consumption per capita*. The maximum values of the previous measures can also express the *annual production capacity* of a water supply system. System capacity is also be defined by (i) the maximum rate of water production and (ii) the maximum flow of each pipe. In principle, pipes are designed for a maximum flow that satisfies fire extinguishing water demand –to be delivered through hydrants– and which is required by fire departments. This flow is significantly larger than the maximum instantaneous water demand for other uses, roughly of the magnitude of six to twelve times larger. Thus, distribution networks with hydrant provision are oversized relatively to the capacity needed for the delivery of water only for consumption. Operational rules and protocols define the rate of water production and other parameters or actions that ensure good water quality and continuity of supply under oscillating water consumption and fixed infrastructure (see §3.1). Deviations in the rate of production and the rate of consumption are regulated through *reservoirs* (also referred to as *tanks*).

A significant parameter to be commented upon is the different temporal dynamics of change in an urban environment and the multi-stakeholder environment of an urban water supply system. The life cycle of main components of the water supply system are of the magnitude of several decades, sometimes exceeding a century. This is typically shorter than the life cycle of an urban fabric, where spatial zoning –in terms of street location and building location– changes at very low rates if at all. On the other hand, the life span of a water supply system is longer than the life cycle of water consuming appliances and building installations, such as faucets, washing machines and domestic piping systems. Adding to the complexity, dynamics at different levels are controlled by multiple stakeholders. As was already mentioned, the water utility and the local fire department determine the design and capacity of the water supply system, that is to some extent determined by the presence of fire hydrants. Local and regional authorities determine the city dynamics (with the contribution of urban planners), a type of information that is often publicly available. Individual users and owners make decisions about their water consumption and water equipment, which they acquire from suppliers and they have installed by contractors. It becomes clear that the multiactor environment leads to a situation of *asymmetric information*. Users know all the details about their behaviour in terms of water consumption: the timing, the duration and the type of water use. Owners are aware of the water consuming equipment in a building, whereas suppliers and contractors hold a lot of information about installed equipment and trends in building renovation. This knowledge is not directly available to the water supplier, that has access to aggregate and statistical values of water consumption and, in the best case, similar data about appliance use. The above are roughly presented in Table 3.

TABLE 3 TEMPORAL DYNAMICS (ROUGH ESTIMATION) AND MAIN ACTORS OF CHANGE AND RENOVATION IN AN URBAN ENVIRONMENT: BUILDINGS AND WATER SUPPLY SYSTEM

Levels of change	Dynamics/ Life span (in years)	Main actors
Behaviour of users	<20	Users
Appliances	<30	Users Owners Suppliers
Building installations	20-50	Users Owners Suppliers Constructors
Fire Hydrants	20-50	Fire department Water company
Distribution pipes	20-150	Water company Fire department
Transport & treatment	50-100	Water company
Spatial planning & building shells	>100	Local authorities National authorities

3.1. Redundancy and operations of water supply systems

System architecture aims at constant supply of good-quality water both through the technical design and the operational rules and protocols. Water supply system technical design is characterized by redundancy and back-up systems (National Research Council, 2006). Typical examples are the *looped* design of distribution systems, that allows for water to flow from many directions, the provision for multiple fresh water sources and the construction of double or triple water pipes in critical areas of transfer or distribution.

The previous indicate that a water supply system can be operated in more than one ways and that operational rules are necessary. The latter ensure that the system is working in a cost-effective and controllable way. Certain rules allow space for initiative and judgement to operators and managers, whilst others are embedded in software or automated systems whose design principles are not necessarily known to the actors that apply or monitor them. The latter become increasingly popular as technological capabilities become cheaper and more advanced.

Table 4 includes the main design principles and operations that ensure the satisfaction of the objectives of a water supplier that were previously presented. Understanding the possibilities is essential in order to search for mitigating tactics and alternatives to overcome performance degradation. The table was built by systemizing information by multiple sources (Van der Kooij, 2003; Hall et al., 2009; Waternet, 2012; "Design of drinking water distribution network," 2013), whereas most of the design elements and operational rules presented are self-explanatory. The *"self-cleaning" branched distribution network*, the *avoidance of hydrant provision*, the *cleaning of pipes* and the *flushing of pipes* are specialized practices regarding water supply systems and are, thus, explained below. *Water demand management* aims at ensuring security of supply and is discussed briefly in §3.3. The overlap of certain operationalized criteria (see Table A - 2 of the Appendices) results in the repetition of a small number of table entries under different objectives.

TABLE 4 MAIN TECHNICAL DESIGN PRINCIPLES AND MAIN OPERATIONS PER OBJECTIVE

Good drinking water quality	Good quality of service	Good financial balance	High level of safety
• Multiple sources • Multiple treatment plants • Parallel treatment units • Connections amongst redundant components • "Self-cleaning" branched distribution network • Avoidance of hydrant provision	• Multiple sources • Multiple treatment plants • Parallel treatment units • Multiple transportation pipes • Multiple mains • Multiple pumping stations • Looped distribution network • Multiple inlet points	• Design based on water demand forecasting	• Multiple sources • Multiple treatment plants • Parallel treatment units • Multi-barrier treatment process
• Cleaning of pipes • Flushing of pipes • Water quality measurements • Control valve inspection • Addition of residual disinfectants	• Risk analysis of component failure • Maintenance, repair or replacement of risky components • Preventive cleaning of pipes • Customer satisfaction surveys • Water demand management	• Abstraction and treatment rates optimization • Pumping rate optimization • Asset management • Risk management	• Cleaning of pipes • Water quality measurements • Control valve inspection • Risk analysis of pipe burst • Risk management

Pipe cleaning is a wide spread operation applied to distribution networks that contributes to maintaining high water quality. The purpose is to remove sedimentation that has accumulated within the pipes and which is a common phenomenon. The fluctuation of water consumption (see §3.2) and the alternation of the direction of flow in looped networks lead to instances of low or zero flow velocities and, subsequently, to particle sedimentation within the pipes. The degree of sedimentation depends on the local flow regime. In turn, accumulated sediment can cause water discolouration due to sediment re-suspension. Removing the sediment by scheduled cleaning programs prevents these effects. *Flushing water pipes*, which is one method of pipe cleaning, can also serve as a way to force high water velocities and ensure short(er) residence times when needed. One example is the execution of flushing programs in order to prevent frosting of water in low velocity areas (that are typically characterized by low water consumption) (Waternet, 2012).

A relatively new design principle suggests that distribution systems should be *branched* (also referred to as "*self-cleaning"*) in order to prevent discolouration incidents and extensive residence times (Blokker et al., 2007), however elements of this principle have been criticised through other studies[1] (Husband and Boxall, 2011). Oversized pipes exacerbate the phenomena of quality degradation due to the above mechanisms (Vreeburg, 2006; Vreeburg and Boxall, 2007). As discussed earlier, *hydrant provision* leads to oversized distribution pipes. The removal of hydrants from distribution systems has been increasingly discussed not only because of water quality issues, but also because fire-fighting technology has been advancing (Fire department of Amsterdam-Amstelland, 2012; Waternet, 2012). However, budget that would allow the expansion of new technologies has not yet been allocated (Fire department of Amsterdam-Amstelland, 2012).

3.2. Water uses, water consumption and water saving

Water consumption depends on the instantaneous use of water and is variable throughout the day and year depending on the temporal patterns of human activities and water needs. To elaborate with two examples, statistical analyses indicate that water consumption is relatively high early in the morning and early in the evening (see Figure 6) and typically higher on warm days than on cold days (see Figure 7).

In an existing system the (urban) water consumption is monitored through the produced water that enters the distribution system. This value can be instantaneous or aggregate. The aggregated value of produced water exceeds the total consumption since it includes *unaccounted-for water*, such as leaked water and water used for fire extinguishing, pipe cleaning and, sometimes, municipal or public uses. A more accurate figure of the aggregate consumed water by customers is generated through the summation of invoiced water volume, both retail and wholesale.

[1] The study of (Gemeente Amsterdam, 2003) indicates that the *self-cleaning velocity*, that the branched distribution systems are designed with, is sufficient only for certain types of pipe material.

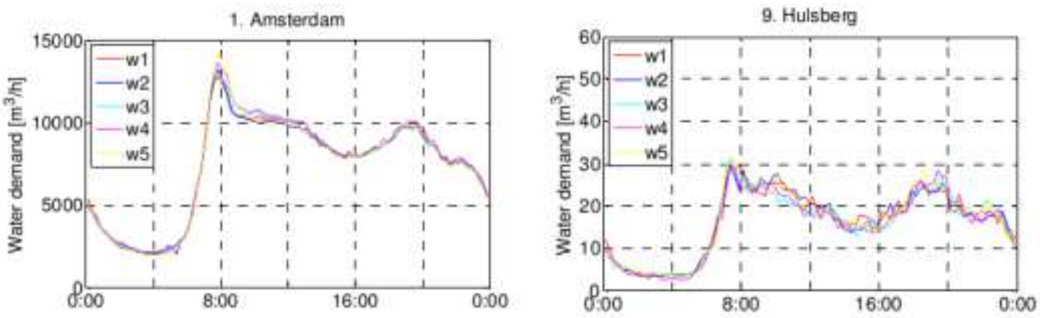

FIGURE 6 HOURLY WATER DEMAND FLUCTUATION IN A LARGE AND A SMALL CITY OF THE NETHERLANDS – DATA OF 5 CONSECUTIVE NON-HOLIDAY MONDAYS (BAKKER ET AL., 2012, P.4)

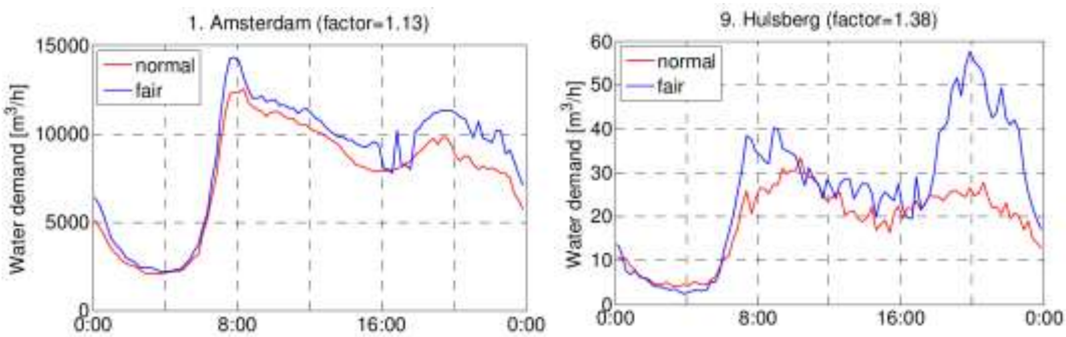

FIGURE 7 HOURLY WATER DEMAND FLUCTUATION ON TWO NON-HOLIDAY MONDAYS WITH TEMPERATURE DIFFERENCE IN A LARGE AND A SMALL CITY OF THE NETHERLANDS – NORMAL: TMAX=12,4°C, FAIR: TMAX=26,8°C (BAKKER ET AL., 2012, P.5)

Retail sale refers to households and businesses that receive their water through the distribution system and is the counterpart to *wholesale* (or *en-gros* sale) that typically takes place upstream of the distribution system. Besides household and business use, water circulating in the distribution system may serve purposes such as fire-fighting, pipe cleaning and others, as mentioned before. Water sold to industrial customers, when available, is used for production processes in large amounts and is not treated to meet the standards of the distributed water.

Figure 8 presents schematically typical household water uses, whereas Table 5 supplies an overview of the average household consumption per use in the Netherlands. Drinking water is sold to the consumers and the revenues are used to cover distribution and production costs. In households with installed *water meter*s, the water bill depends on the volume of the consumed water. In households where a water meter has not (yet) been installed, billing depends on other elements, such as the number of residents and the type and number of rooms (Waternet, 2012). Even though water price is widely discussed as *inelastic*, research indicates that there is some elasticity and that water consumption can be influenced, under circumstances, by the water price (Olmstead et al., 2007; Dharmaratna and Harris, 2012). The installation of water meters has been associated with a decrease in the amount of water consumed (Willis et al., 2010, 2011; Waternet, 2012). For the above reasons, the relation between consumption and invoice on Figure 8 is bidirectional. As is indicated in Table 5, showering, toilet flushing and laundry are the most water-consuming uses. The appliances corresponding to each use, the duration of the use and the frequency of the use determine the actual amount of water that is consumed.

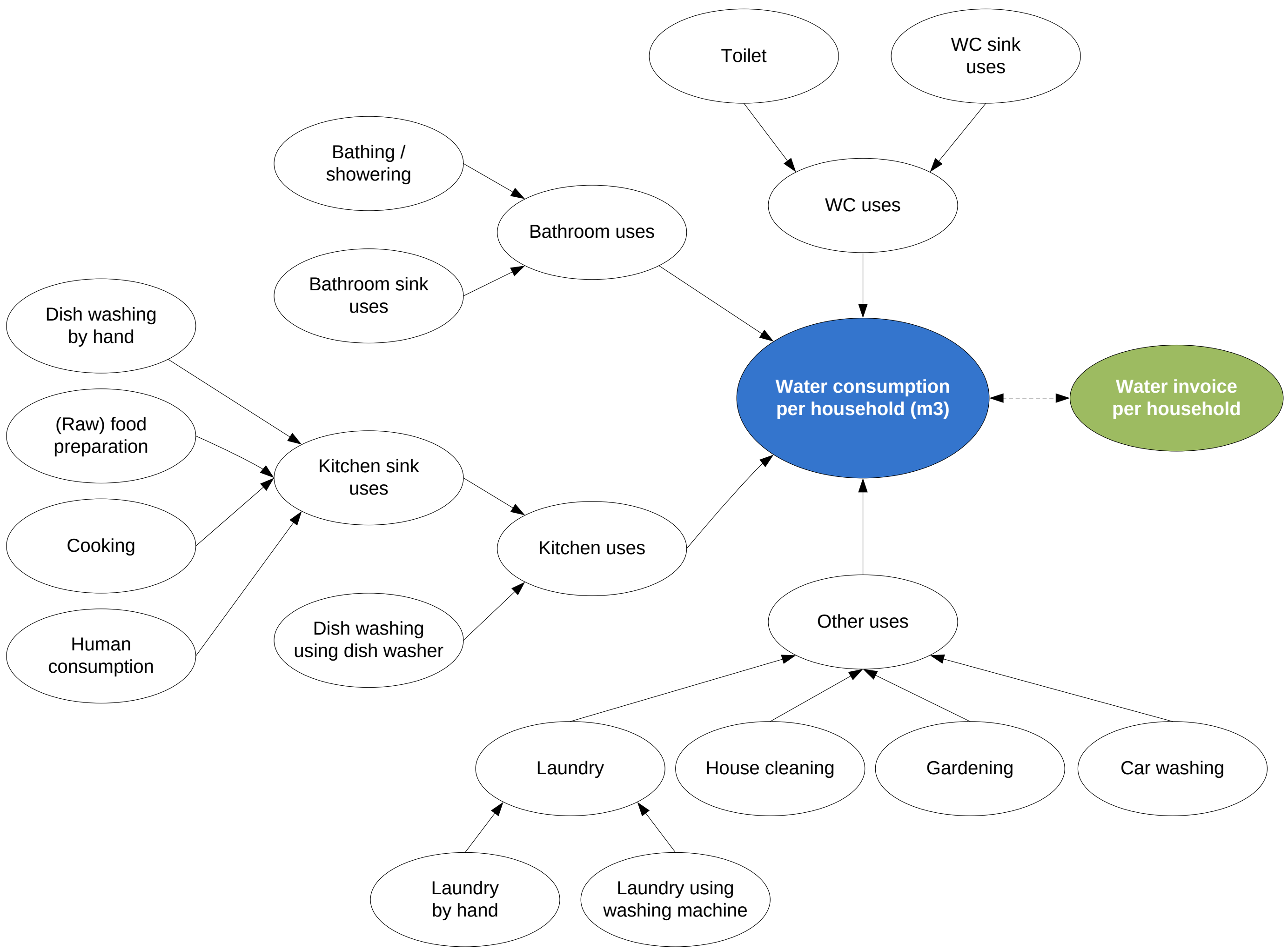

FIGURE 8 TYPICAL CONSTITUTION OF THE WATER CONSUMPTION OF A HOUSEHOLD

TABLE 5 AVERAGE HOUSEHOLD CONSUMPTION PER CAPITA IN THE NETHERLANDS (KLOOSTERMAN ET AL., 2011, P.44) [*TRANSLATED FROM DUTCH*]

Water use	Consumption (l/h/d)[2]	Percentage
Bath	2,5	2,0
Shower	49,8	39,1
Sink	5,3	4,2
Toilet flush	37,1	29,1
Laundry (by hand)	1,7	1,3
Laundry (machine)	15,5	12,2
Dish washing (by hand)	3,8	3,0
Dish washing (machine)	3,0	2,4
Food preparation	1,7	1,3
Kitchen faucet (other uses)	7,1	5,6
Total	**127,5**	**100**

Water consuming technologies and appliances vary. Suppliers offer products of variable water efficiency, such as washing machines or toilets and appliance design tends to become more water efficient. Also, systems have been designed that allow the use of other water sources –additional to the distributed water– for instance the use of harvested rainwater and treated wastewater. Attempting to systemize the ways in which water saving can be achieved by retail consumers, three types of change can be identified: *behavioural change* (different habits), *technology upgrade* (more water-efficient appliances) and *installation upgrade* (using a new system, such as rainwater harvesting or greywater recycling, in order to substitute or complement the previous water source of the building). Figure 9 indicates how water saving can be achieved through behavioural change and appliance upgrade. Every type of water use has some potential of consumption reduction. The reader, however, should have in mind that water aware appliances may lead to more careless behaviour of the users, such as longer showers or more frequent use of water consuming appliances (Jefferson et al., 2012). Figure 10 reproduces the paradigm of a house in Sydney where source substitution installations rendered the house self-sufficient (“Sydney’s Sustainable House: how to live like a tree,” 2009).

[2] Litres per head per day

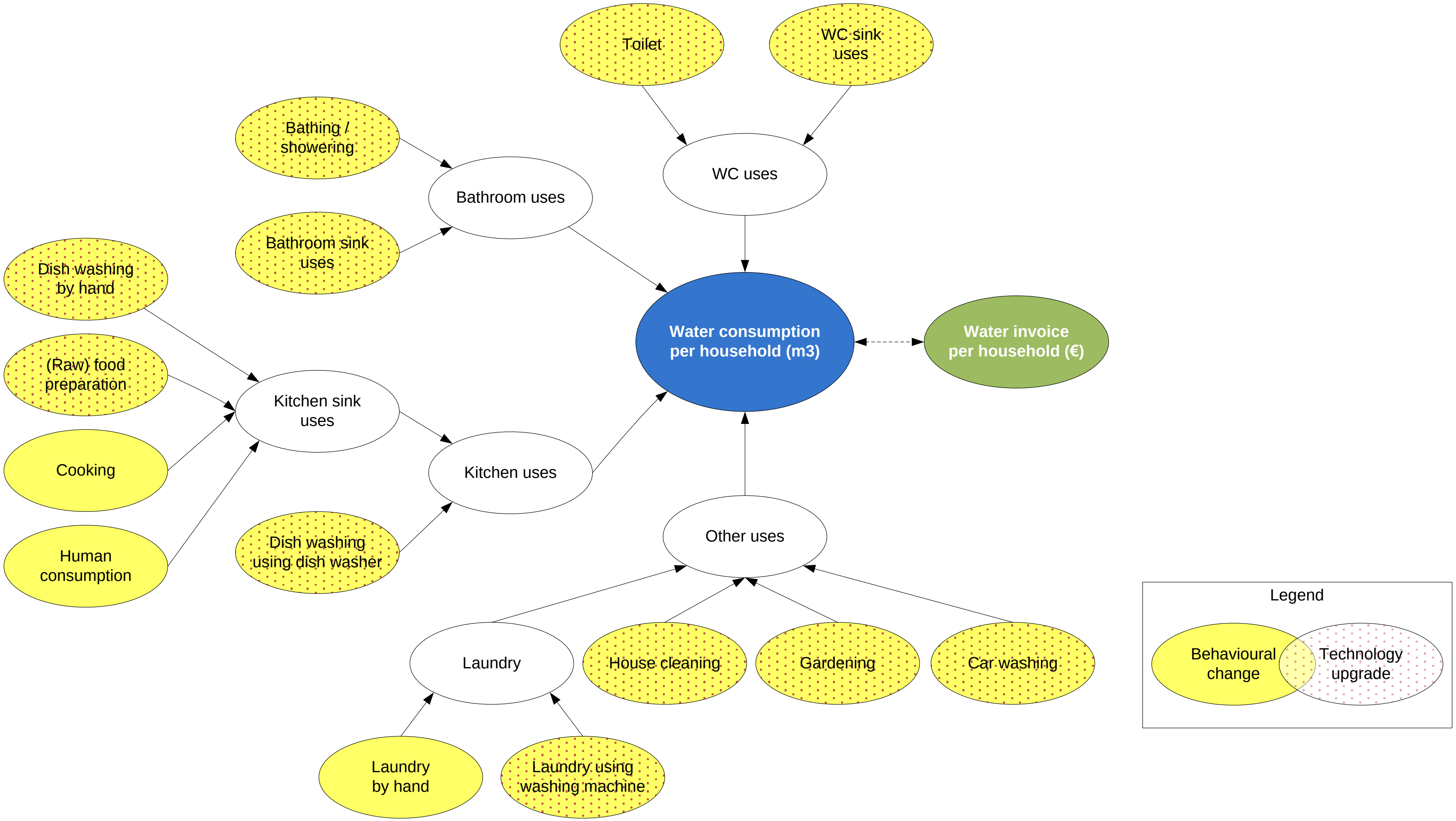

FIGURE 9 WATER CONSUMPTION AT HOUSEHOLD LEVEL: WATER SAVING WITHOUT SOURCE SUBSTITUTION

FIGURE 10 WATER CONSUMPTION AT HOUSEHOLD LEVEL: AD-HOC COMPLETE SOURCE SUBSTITUTION IN SYDNEY, AUSTRALIA; BASED ON ("SYDNEY'S SUSTAINABLE HOUSE: HOW TO LIVE LIKE A TREE," 2009)

Installation upgrade can have a large impact on water consumption: a single rainwater harvesting system used for toilet flushing can reduce household water consumption by about 29% if the precipitation regime allows it, whereas a combination of rainwater and greywater systems that could be used for toilet flushing and laundry can lead to a reduction of about 40%[3] (see data of Table 5). Technology upgrade can have a large impact as well, comparable to the above. Flow limitations in showers and faucets, more efficient toilet design, water aware washing machines and dish washers, can reduce the consumption of the equivalent uses. To indicate with a few figures, flow limitations for showers and faucets can cause a reduction of flow of up to 60% and 30% respectively (*Focus on Sustainability - Hansgrohe sets Standards*, n.d.), accounting for about 26% of the household water consumption if the frequency and duration of use remains stable. Tenorio (2012) indicates a possibility to save 90% of water for toilet flushing by installing vacuum toilets, 40% by installing new types of faucets and showers and 50% by water aware dish washers, amounting to a total of 47% reduction of household consumption (21% if vacuum toilets are not installed[4]). Behavioural change can also affect consumption. Dworak et al. (2007) mention that, for the case of the United Kingdom, water consumption during showering can be reduced by 30% by changing the prevalent bathing regime and water consumption by washing machines can be reduced by about 50% by using the appliance only when full. If the same figures would apply in the Netherlands, they would amount to about 18% of the household consumption. The latter figures are mentioned here only for reasons of illustration and should be examined further in order to be used in a quantitative analysis.

Water demand is variant not only in time, as mentioned earlier, but also is space. The demand throughout a distribution system is not uniform as customer types and demographic characteristics vary. Each type of customer, for example a hotel, a restaurant, a hairdressing salon, a carwash or, simply, a household, is characterized by different typical uses. Different needs, technologies and individuals induce different water consumption. For example adults, children and teenagers have been statistically related to different habits of water use (Bennett et al., 2013). Different household typologies (Makki et al., 2011; Willis et al., 2011), household income (Makki et al., 2011; Willis et al., 2011; Bennett et al., 2013), educational level (Makki et al., 2011) and cultural backgrounds (Waternet, 2012) have been observed to influence the level of the water consumption. The water efficiency of installed appliances is also determinant of the household water demand (Willis et al., 2011; Carragher et al., 2012; Bennett et al., 2013). Keeping in mind that both the habits of individuals and their household appliances determine water consumption (Makki et al., 2011), one should not jump into further conclusions about the single relations between demographics and habits or demographics and housing appliances.

[3] As mentioned in Chapter 4 regulation currently allows only rainwater harvesting systems to be installed for toilet flushing.

[4] The technology of vacuum toilets seems to have not yet advanced enough to maintain the performance levels of conventional toilets, for example in terms of the generated smell k. The ultimate .

3.3. Water saving drivers

One would expect that the above differences in consumption regime could also reflect in differences regarding possible water saving in the future. However, there seems to be no sufficient scientific evidence to support such an assumption. Even though demographic characteristics have been scientifically related to different water consumption regimes, the same cannot be claimed for the adoption of a *water saving* attitude in the future.

In the abundant literature about water reclamation and reuse that attempts to link demographic characteristics to the willingness of consumers to use recycled water, findings are contradicting. Some researchers indicate that demographic characteristics such as age, gender and employment status are related to the openness towards recycled water uses, whereas others have found no statistically significant relation in their studies (Friedler et al., 2006). An overview of such publications is supplied by Dolničar and Saunders (2006) who point out that research in the field can be improved in a number of ways in order to supply better insights on community openness to water saving and sustainable technologies. For example, focus on real case studies instead of hypothetical questions to the users, consistent explanation of the statistically significant relations and replication/validation of old studies are mentioned.

A prominent way to achieve water saving, is through *water demand management* strategies that water companies and governments build. Smart water metering, pricing deviations by use type and consumption level, taxation, water-quota regulations, labelling, subsidization and education of users have been suggested in literature as suitable water demand management techniques (Mohamed and Savenije, 2000; Dworak et al., 2007; Kampragou et al., 2011; Carragher et al., 2012). The above are typically applied in water scarce areas where population is rising and concerns about the security of water supply arise. The extensive research on how to affect the *patterns of water use* and *levels of water demand* (American Society of Civil Engineers, 1998; Savenije and van der Zaag, 2002) indicates that changing consumption regimes and achieving water saving is not easy. Residents that have adopted water reuse schemes in the United States of America and Australia considered that “cost savings”, “positive effects on the environment”, “not wasting potable water”, “nutritional value of the reclaimed water to plants”[5] and “satisfaction with their role in conserving water” are, in sequence, the most “significant benefits of reusing water”, denoted by at least 20% of the respondents (Friedler et al., 2006, p. 361). It should also be noted that incentives to promote water aware design and appliances in buildings –not aiming at the actual (metered) water consumption– can actually become an incentive for higher water consumption through the change of the behaviour of the users towards the opposite direction (Jefferson et al., 2012). It has also been observed that people who have environmental concerns, tend to also engage in some type of water saving (Dworak et al., 2007). Conducting information campaigns has also been suggested as a way to induce a reduction of the water consumption (Rijksoverheid, 2013b; UNESCO, 2013).

According to the literature review of Brown and Vergragt (2008), a rapid change towards sustainability in buildings demands that “the professions and other communities of practice

[5] Reclaimed water is widely used in these areas for gardening

linked to building design, construction, and maintenance fundamentally reconsider some of their norms, practices, and problem definitions" (Brown and Vergragt, 2008, p. 110). Some researchers suggest governmental policy reforms as the main tool to induce institutional and behavioural changes towards this end, whereas others consider a change of lifestyle and value system also imperative (Brown and Vergragt, 2008). Particularly when discussing sustainable use of water, water demand management measures indicate that governmental intervention is the prominent tool, particularly in urgent times (see references on *water demand management* above). Abrupt new policies can bring about sudden changes in building code and, hence, water consumption (Waternet, 2013). Nonetheless, transitions towards sustainability tend to be time consuming, as can be indicated by the long-term context of transition management of 25-50 years (Loorbach and Rotmans, 2006).

Ideas for behavioural change, new designs, innovative technologies, even decision support tools have been developed to facilitate the transition towards less water consuming urban environments (Turner and White, 2003; Sydney Water, 2007; Makropoulos et al., 2008; "Future We Create- Part I: The Big Picture, Dr. Mark C.M. van Loosdrecht," 2013). Regulations vary and, typically, set restrictions to the type of (domestic) water source that can be utilized for each household use. For example in the Netherlands harvested rainwater is allowed to be used for toilet flushing (see §4.2) but recycled greywater cannot be utilized, wherea in Australia recycled greywater water is used for various household uses (mostly toilet flushing and gardening) (Mainali et al., 2011). At the same time, technology advances rapidly and further innovations in (waste)water treatment are not out of the question.

One reason that *water aware* equipment and design has been gaining increasing popularity are the global concerns for water scarcity and the need to preserve water resources (UNESCO, 2013). Another reason, profound in academic publications with regard to rainwater harvesting and wastewater reuse, is the wish to moderate urban drainage and sewage systems[6]. The European Commission has included water usage monitoring and water consumption decrease in the point system of the Community Eco-labels for buildings (*Establishing the ecological criteria for the award of the Community Eco-label for Buildings*, n.d.). One should not ignore the personal awareness and sensitivity about the environment, which can become a trigger of commitment to water saving (Dolničar and Saunders, 2006). A user may also wish to engage in reducing water consumption and installing new technologies in order to be independent ("Sydney's Sustainable House: how to live like a tree," 2009; Waternet, 2013).

The above have been "translated" into *potential drivers of water saving* and are summarized in Table 6. The drivers have been systemized in categories of behavioural change, technology upgrade (appliances) and installation upgrade (domestic water source substitution). In principle, no literature was found mentioning drivers that could lead to water demand reduction without external intervention such as water demand management measures. Thus, supplementary to regulatory drivers, others have been identified through reverse thinking on the literature of water demand management (see indicative publications

[6] For further elaboration by the reader, the following indicative concepts are mentioned: *Sustainable Urban Drainage Systems* (SUDS), *Integrated Urban Water Management* (IUWM), *Water Sensitive Urban Design* (WSUD)

above), on information about successful and unsuccessful sustainability pilot projects (Hegger et al., 2008) and on opinions of interviewees (Waternet, 2012). As mentioned earlier, environmental awareness can be a driver of water saving. However, as Congreve (2012) mentions, one of the reasons that sustainable communities are not engaged by the wide public is that *self-interests* are not promoted – instead, *self-sacrifice* is largely encouraged when sustainable technologies and ideas are being promoted (Congreve, 2012). Following similar reasoning, unprompted water saving is expected to stem from some *gain* in comparison to the present regime. Otherwise, people lacking environmental sensitivity have no incentive to change their habits or to finance new equipment. Towards this reasoning several drivers of Table 6 have stemmed from reversing *barriers*. For example, the high cost of installation of greywater harvesting systems is currently a barrier to their expansion, whereas if the cost is low, a building owner who plans to refurbish her building is directly incentivised to install them. Additionally, the prohibition of greywater systems is currently a barrier for the use of such technologies in the Netherlands. Allowing them constitutes no incentive for their installation. A new building code however, that would render additional water sources in buildings a legal requirement, is clearly a driver for water demand reduction (Waternet, 2013).

TABLE 6 DRIVERS OF WATER SAVING BY RETAIL CONSUMERS, PER TYPE OF CHANGE

Type of change in consumption regime	Financial/regulatory drivers	Social drivers	Technological drivers
Behavioural change	Economic crisis / willingness to decrease water budget Change in pricing regime Metering Water consumption quota	Increased environmental concerns Awareness of climate change Social trend (lifestyle change)	-
Technology upgrade (appliances)	Life cycle of current appliances Building refurbishment Labelling/certification (increased value of property) Low energy consumption Low cost of purchase and installation/short payback period Subsidization Economic crisis / willingness to decrease	Increased environmental concerns Awareness of climate change Social trend Social image/brand Willingness to be self-sufficient	Better performance (noise, smell, duration of operation, others) Lower maintenance needs Better appearance

	water budget Change in pricing regime Water consumption quota		
Installation upgrade (in-building water source substitution)	Legal requirement Life cycle of building installations Building refurbishment Labelling/certification (increased value of property) Low energy consumption Subsidization Low cost of purchase and installation/short payback period Change in pricing regime Water consumption quota	Increased environmental concerns Awareness of climate change Social trend Social image/brand Willingness to be self-sufficient	Better performance (technological breakthrough)

Chapter 4. The water supply system of the Metropolitan Area of Amsterdam – infrastructure and stakeholders

This chapter supplies basic information on the case study.

Waternet, that operates in and around the City of Amsterdam, is responsible for the whole water cycle, namely drinking water supply, sewerage and water management (Geudens, 2010). The drinking water supply system, where the thesis research focuses, is operating with high reliability and efficiency through a (regionally) centralized system (Vewin, 2013), however, it is functioning in under-capacity. The drinking water supply was 86,5 million m^3 in 2010, with a capacity of 101 million m^3/year, whilst there is a monitored decreasing trend in average consumption. The value of 2012 was 136 L/inhabitant/day in 2012, less than forecasted value of the 2010 estimation (see Figure 11). This trend has raised concerns about the future of the water supply system. The reasons for the drop are not clear, however the decrease has been linked to (i) the installation of meters, that increase the awareness of users on the amount of water that they consume and pay for, and (ii) on the improved technology of washing machines and dish washers (Waternet, 2012). Noticeably, the average drinking water consumption is significantly lower than the European average that is approximately 200 L/inhabitant/day (World Water Council, n.d.).

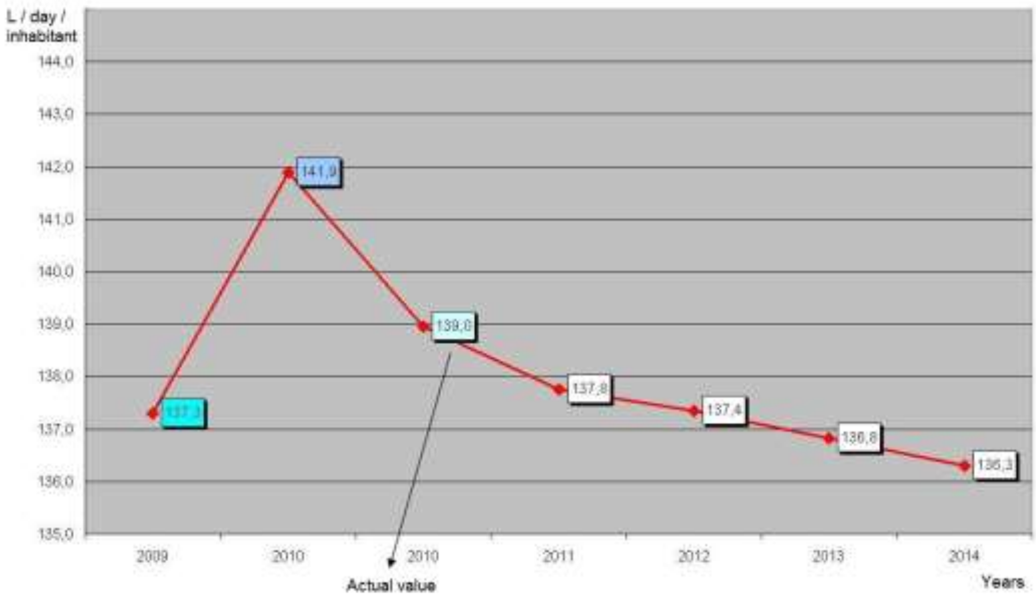

FIGURE 11 DECREASING TREND OF WATER CONSUMPTION IN THE METROPOLITAN AREA OF AMSTERDAM (WATERNET, 2010) [*TRANSLATED FROM DUTCH*]

Water supply in the Metropolitan Area of Amsterdam is realized through two separate chains of abstraction and production that provide water to the same, unified, distribution system, namely the *Leiduin chain* and the *Weesperkarspel chain* (Waternet, 2012, n.d.). Water is abstracted, treated and distributed, as is schematically indicated in the horizontal chains of water supply of Figure 12. More details on the structure and assets of the production system are supplied through the map of Figure 13 and Table 7.

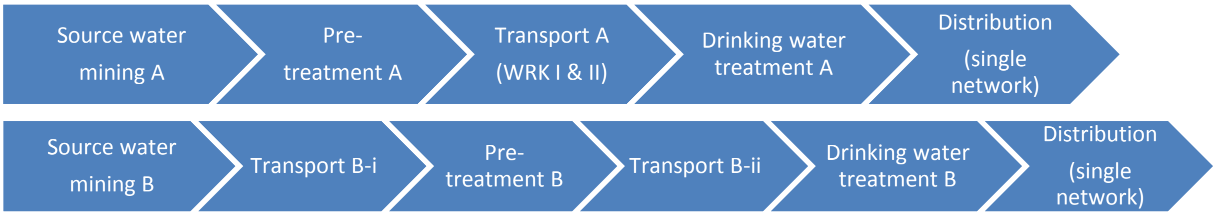

FIGURE 12 CHAINS OF WATER SUPPLY OF THE METROPOLITAN AREA OF AMSTERDAM – A: *LEIDUIN CHAIN* AND B: *WEESPERKARSPEL CHAIN*

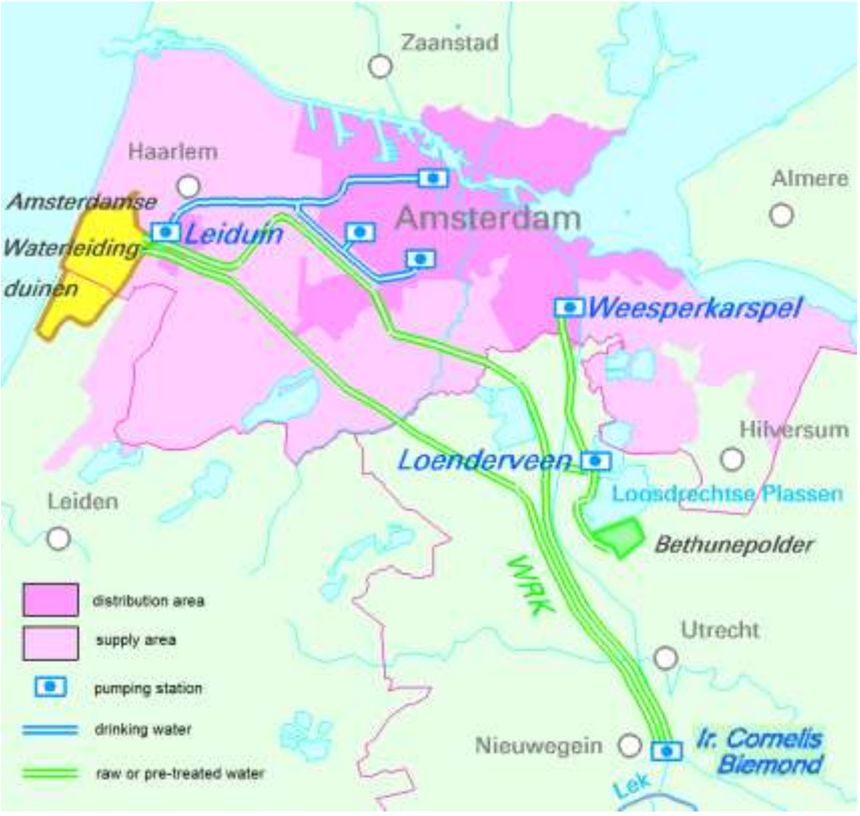

FIGURE 13 MAP OF THE WATER SUPPLY SYSTEM OF THE METROPOLITAN AREA OF AMSTERDAM (WATERNET, N.D.) [*EDITED AND TRANSLATED FROM DUTCH*]

TABLE 7 MAIN PHYSICAL ENTITIES OF THE WATER SUPPLY CHAINS OF THE METROPOLITAN AREA OF AMSTERDAM

	Sources	***Pre-treatment***	***Drinking water treatment***
Leiduin chain (A)	*Lek Canal* *Nieuwegein underground acquifer (back-up source)*	*Cornelis Biemond plant*	*Amsterdam Water Supply Dunes (AWD)* *Leiduin plant*
Weesperkarspel chain (B)	*Bethunepolder* *Amsterdam Rhine Canal (ARK) (limited use)*	*Loenderveen artificial lake*	*Weesperkarspel plant*

WRK (*Watertransportmaatschappij Rijn-Kennenmerland*), a co-owned company of Waternet and PWN Waterleidingbedrijf Noord-Holland[7], owns the source mining plant, transport pipes and pre-treatement plant of the *Leiduin chain*. Waternet owns the rest of the water supply system, but maintains the responsibility of operating also the WRK owned parts.

Annually, the *Leiduin chain* supplies about 60 Mm^3 to the distribution system, whereas the *Weesperkarspel chain* supplies about 26,5 Mm^3 [8]. According to the operational rules of Waternet, the *Weesperkarspel chain* operates in a relatively stable manner, whereas the rate of production along the *Leiduin chain* is adjusted in order to regulate the system to demand fluctuations. Both chains are operating in under-capacity, with utilization rates of about 64% and 86% respectively[9]. The distribution system has been designed with respect to the needs of the fire departments in the area, that exceed the needs for drinking water supply to consumers. It is, thus, oversized.

4.1. Water consumption in the Metropolitan Area of Amsterdam

The water supply system delivers two qualities of water, namely drinking water and industrial water. Industrial water is produced along the *Leiduin chain* and is referred to as *pre-treated water* because it has undergone the pre-treatment processes before sale. Drinking water is sold both to en-gros customers (other drinking water companies) and to retail customers (see Figure 14).

FIGURE 14 WATER SALE TYPES AND THEIR VALUES ALONG THE HORIZONTAL CHAIN

Invoicing is primarily conducted through metering the volume of consumed water, however water meters have not yet been installed to a portion of the customers. Water meters in existing buildings are typically installed during refurbishment because a redesign of the piping installations is necessary[10] and Waternet depends largely on the initiative of the building owners to make contact on this occasion (Waternet, 2012). Thus, absence of water meters may indicate that the building has not been refurbished in the past few decades or that the owners did not contact Waternet to have meters installed. In old constructions redesigning piping installations may not be readily feasible, thus water meters cannot be installed (Waternet, 2012). As a result of the above, there is a number of customers whose water consumption is only *estimated* and not metered, fact which limits the already restricted monitoring capabilities of a distribution system, discussed in Chapter 3.

[7] PWN is the water company that operates northern of the jurisdiction of Waternet
[8] Values of 2010
[9] The capacity utilization rates are calculated for the production of high quality drinking water
[10] Indicative designs of metered and non-metered houses in Amsterdam are supplied in the Appendix (see Figure A - 1)

Table 8 summarizes information that was collected and processed about the type, number, consumption and metering regime of the customers of the Metropolitan Area of Amsterdam (Waternet, 2012, n.d.). The consumption of retail customers (households and businesses) accounts for more than 75% of the drinking water and more than 50% of the total water sold, whereas their multiplicity renders their future behaviour as a customer group highly uncertain – no uniform way of acting should be expected. Industrial and wholesale customers are characterized by small numbers of individual customers with high consumption values, thus individual strategies of consumers could be directly identified. Invoicing of most customers is not bounded by contracts, with the exception of the largest individual consumers. The latter are approached for negotiations when the contracts are close to their expiration date (Waternet, 2012).

Looking closer at the figures of Table 8, the following can be observed in terms of the consumption of retail customers. Households consume the 57% of the produced drinking water, equivalent to the 39% of the total water sold (pre-treated water and drinking water). These figures render households the largest aggregate consumer. Business customers consume considerably less, namely 20% of the drinking water and 14% of the total water sold, however their average consumption is about 8 times larger than the average consumption of a single household.

TABLE 8 THE CUSTOMERS OF WATERNET AND THEIR CHARACTERISTICS

	(Approximate) Number of customers	Approximate consumption (Mm^3/year)	Metering regime	Invoicing regime
Households (HH)	480.000	46,5	67,5% metered	- Metered volume - HH characteristics
Small & medium business	20.000	11	98,1% metered	- Metered volume - Business characteristics[11]
Large business	260	5,5	100% metered	- Metered volume
Wholesale (en-gros)[12]	2	18	100% metered	- Contracted volume
Industrial (Westpoort)	20	2	100% metered	- Metered volume - Special arrangements
Industrial (Velsen Noord)[13]	2	35,5	100% metered	- Contracted volume

The above data and discussion indicate that retail consumers are not the only type of customer that can affect future water demand by the water supply system of Waternet. They are,

[11] Only when non-metered

[12] Of this amount, about 5 Mm^3 of water is produced along the Weesperkarspel chain and the rest is produced along the Leiduin chain.

[13] This sale is conducted by WRK

however, characterized by uncertainty that is hard to address due to their multiplicity. The households have been the primary concern of the problem owner at the start of the research. However, the above figures indicate that the future consumption of business users is also characterized by high uncertainty, whereas their impact is not a priori negligible. Their higher average consumption renders them, even, a user category of interest.

4.2. Water saving: actors and legislation

Urban dynamics take place in a complex multiactor environment whose changes are regulated by the state and local authorities. One could say that legislation incorporates the state's perception and understanding of these changes, thus it is important to address and understand it.

The Dutch legislation includes barely any reference to the issues discussed so far. Drinking water tariff per m^3 is stable regardless of the level of water consumption and there are no incentives or anti-incentives to reduce water consumption. According to the Dutch regulation, all water uses in a household need to be satisfied through water of potable quality, with the exception of the so-called *household water –huishoudwater–* that is meant for toilet flushing and can originate from harvested rainwater or groundwater (*Drinkwaterbesluit*, 2011, Art. 1-5). Water for toilet flushing can originate from other sources (undefined by the law) as long as the inspector –*toezichthouder*– allows it. In practice and until today, the inspector has been very reluctant to allow permission for the use of greywater as a source of household water due to recent experience of failure in a dual pipe system in the Netherlands[14] (Waternet, 2012). Thus, under the current regulatory regime greywater recycling cannot be implemented and harvested rainwater use is limited to toilet flush. Until now water saving seems to have not been an issue of high interest for the state. However, regulatory changes are not out of the question, especially when addressing an issue in the long term.

Table 9 brings together the changes that can affect a water supply system in an urban environment (see also Table 3) and the Dutch legislative texts that regulate them. It is important to notice that a number of enactments, not directly related to water, regulate building and urban design. Additionally, the table includes the main stakeholders that can affect change. For example, the extensive presence of housing corporations in Amsterdam –they own and operate more than 50% of the buildings in the area (Waternet, 2012)– render them a strong and influential actor in terms of potential renovations and refurbishments. The latter occasions allow for new piping installations in multiple buildings, possibly simultaneously. Suppliers and constructors are also actors of influence, because their willingness or reluctance to promote certain types of appliances and installations can in turn promote or hinder water saving. The regional and national authorities responsible for spatial planning can determine the frequency and the type of urban renewal or the need for water supply asset relocation in case of large development projects. Taking into account authority policies and market availability, property owners and users are to make the decision of adopting water saving behaviour, appliances or source substitution installations.

[14] For further elaboration by the reader: the incident took place in the *Leidsche Rijn*

TABLE 9 DYNAMICS OF URBAN RENEWAL AMSTERDAM: MAIN ACTORS AND LEGISLATIVE TEXTS

Levels of change	Main actors	Main legislative texts[15]
Behaviour	Users	-
Appliances	Users Individual owners Suppliers Housing corporations	Drinking Water Decree Regulation for Green Projects
Installations	Users Individual owners Suppliers Housing corporations Constructors	Building Decree Regulation for the Building Decree Housing Decree Regulation for Green Projects
Distribution pipes & hydrants	Waternet Fire department(s)	Drinking Water Act Drinking Water Decree
Transport & treatment	WRK (PWN) Waternet	Drinking Water Act Drinking Water Decree
Spatial planning & building shells	City of Amsterdam Province of North Holland Ministry of Infrastructure and the Environment	Spatial Planning Act Spatial Planning Decree Building Decree

4.3.Planning into the future

Long-term demand forecasting is being conducted regularly in Waternet in order to be prepared for the future. As commented upon in Chapter 3, demand forecasting proves to be difficult even when demographic and statistical data are available. To demonstrate with data from Waternet (Waternet, n.d.), a 20-year forecast was conducted in 1999 that generated overestimated demand values for the years to come. Several scenarios of estimating future demand were investigated, whose output values ranged from 92,8 m^3/y to 89,5 m^3/y for 2010. The actual demand drop to 86,5 m^3/y was not anticipated.

Waternet has been working on a Long Term Vision for the drinking water supply. In this context, a number of alternative water supply system designs have been generated in order to prepare

[15] Dutch names of legislative texts in sequence: *Drinkwaterbesluit*, *Regeling groenprojecten*, *Bouwbesluit*, *Regeling bouwbesluit*, *Woningwet*, *Drinkwaterwet*, *Wet ruimtelijke ordering*, *Besluit ruimtelijke ordering*

for potential effects of Climate Change on the natural water resources and/or different scenarios of water demand (±5% over a 20-year period) (Hofman et al., 2008). In these alternatives, different water sources and treatment plants have been combined, all of each are technically feasible. The costs of the alternatives, however, have not yet been estimated. In a second part of the same Long Term Vision (Rook et al., 2011) the effort is made to address more future uncertainties and timelines are created that entail potential points of abrupt change. Included events are contract expiration of main customers, alteration of governing bodies and long term policy formulation by European, national and regional authorities. Future water demand variations are mentioned as an issue of interest, but are not addressed.

In terms of the long term finances of the water supply system, it is important to keep in mind that old capital investments have been paid out to a large extent, however additional investments have recently been made to support automation and remote control systems (Waternet, 2012). Additionally, the performance of the distribution system is high and no particular new investments are expected in the near future (Hillegers et al., 2010). The latter do not include maintenance needs.

Chapter 5. Implementation

This chapter contains the uncertainty analysis and system analysis of the water supply system of the Metropolitan Area of Amsterdam with a focus on the driving forces and the effects of demand decrease. The main structure of the chapter follows the scheme "cause-effect-solution". Thus, the causes-drivers of a decrease in retail consumption are firstly discussed. Then the effects on the system performance are identified in a qualitative way. Mitigating alternatives are presented with a focus on the techno-economic system that lies, largely, on the control of Waternet.

The drivers of water saving that were presented in Table 6 of Chapter 3 are here classified according to their uncertainty and impact. This classification enables Waternet to focus on the critical drivers, i.e. the drivers that are either very unpredictable or that may generate a significant demand decrease. Following this classification, actions of stakeholders that are linked to these drivers are identified. For example, there are stakeholders that can promote these drivers –think of an actor that can supply subsidies for new appliances– or that can adopt change which would lead to a high impact –think of a housing corporation deciding to install rainwater harvesting systems in a large number of their buildings.

After discussing the above as "causes" of water demand drop, the effects for the whole technical system are identified in a qualitative way. The system is decomposed into pre-treatment, treatment and distribution subsystems and effects on each one are identified. Notice should be given to the fact that the distribution system cannot be fully monitored. Mitigating alternatives for dealing with these effects in a techno-economic way are supplied afterwards. Thus, solutions focus on the system and the effects and not on the driving forces (see also Figure 2, Chapter 2).

5.1. Classification of the drivers of water saving in the Metropolitan Area of Amsterdam according to their uncertainty and impact

The drivers of water saving presented in Chapter 3 (see Table 6) are critically viewed for the case study of the Metropolitan Area of Amsterdam. The long term character of strategic planning calls for a time horizon of at least a few decades when discussing these drivers. As was proposed in Chapter 2 (see Table 3), within a few decades water demand in buildings may undergo changes in several levels, namely user behaviour, installed appliances and building installations. The dynamics of these changes are not easy to predict, fact which renders changes quite uncertain. An exploration of plausible futures could offer significant insights and the classification of the driving forces could supply a stepping stone for a contextual scenario analysis towards this end (Enserink et al., 2010). It should be kept in mind that scenarios should also take into account demographic developments that are not discussed here.

In Table 10 the drivers of water saving are classified according to their uncertainty and impact into a 3x3 matrix of *high*, *intermediate* and *low* estimated values. Usually, driving forces of contextual change are classified into a 2x2 matrix of high and low estimated values. In this case, however, the complexity and multiplicity of the drivers would render a 2x2 table quite rough, fact which would lead to a loss of information. The reasoning of the classification is explained in the next two paragraphs, followed by an elaboration of the reasoning for every classified driver. Noticeably, no drivers of both low uncertainty and low impact were identified. This was not intended, it forms however a confirmation that the drivers that were retrieved from literature and interviews are, indeed, of interest for Amsterdam.

TABLE 10 CLASSIFICATION OF WATER SAVING DRIVERS BY THEIR IMPACT AND UNCERTAINTY FOR THE METROPOLITAN AREA OF AMSTERDAM (B: BEHAVIOURAL CHANGE, T: TECHNOLOGY UPGRADE, I: INSTALLATION UPGRADE – SEE ALSO TABLE 6, CHAPTER 3)

	High uncertainty	Intermediate uncertainty	Low uncertainty
High impact	Social trend/life-style change (B, T, I) Legal requirement for source substitution Better performance (technological breakthrough) (I)	Labelling/certification (increased value of property) (T, I) Building refurbishment (T, I)	Water consumption quota (B, T, I) Subsidization (T, I)
Intermediate impact	Increased environmental concerns (B, T, I) Awareness of climate change (B, T, I) Willingness to be self-sufficient Better performance of appliances (noise, smell, duration of operation, others)	Life cycle of building installations Life cycle of current appliances Social image/brand (T, I)	Change in pricing regime (B, T, I) Metering
Low impact	Economic crisis / willingness to decrease water budget (B, T)	Low energy consumption (T, I) Low cost of purchase and installation/short payback period (T, I) Better appearance (T)	

The classification in terms of the impact of drivers is based (i) on the extent of the driver's influence, i.e. the fraction of users or owners that could seek to decrease (their) water consumption as a response to that driver, and (ii) on the type of change that the driver can bring about, namely behavioural change, technology upgrade, installation upgrade or a combination of the former. As discussed in §3.2, installation upgrade can generate the highest degree of water consumption reduction. Technology upgrade can generate a smaller, yet comparable, impact, however it may also incentivize a more careless water use in general. Behavioural changes generate the lowest, yet non-negligible, impact. Obviously, drivers that could lead to a combination of the above, will have an even larger impact on the value of water demand. The above reasoning is schematically summarized in Figure 15.

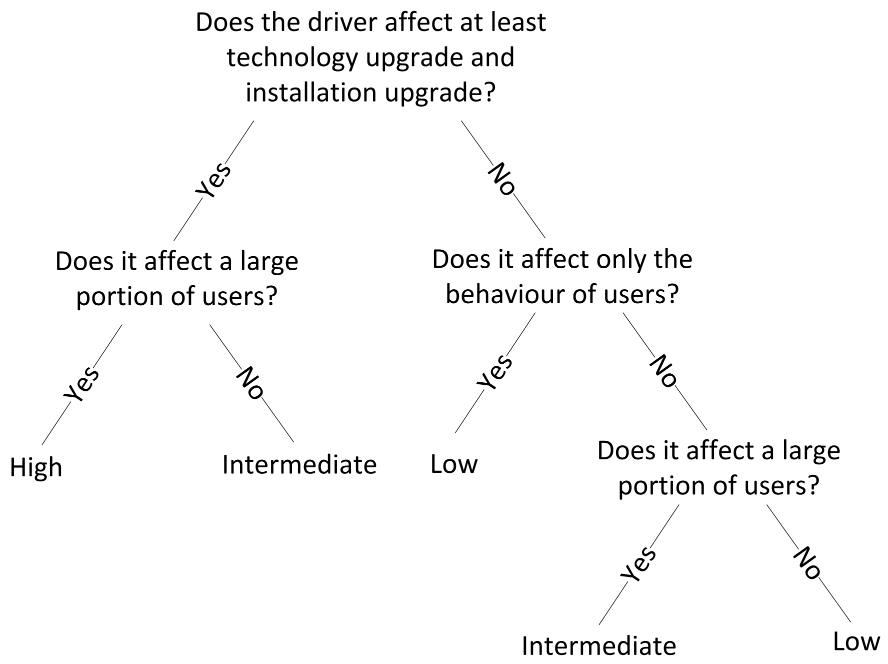

FIGURE 15 CLASSIFICATION SCHEME OF THE IMPACT OF DRIVERS

In terms of uncertainty, the classification is based on the degree of predictability of the driver. It is important to understand that the classification is based on whether the driver is predictable at *the present*. The predictability and, hence, the uncertainty of the drivers may be different if more information or new scientific knowledge becomes available in the future. High uncertainty signifies that it is not possible to assess whether a driver is likely or unlikely to occur. There is a possibility that it could realize in the future, but there seems to be no information or knowledge to assess this likelihood. Low uncertainty drivers can be assessed as likely or unlikely, according to the information currently available. They are somewhat predictable, however they still entail a degree of unpredictability as the future is impossible to foresee. The above reasoning is summarized on Figure 16.

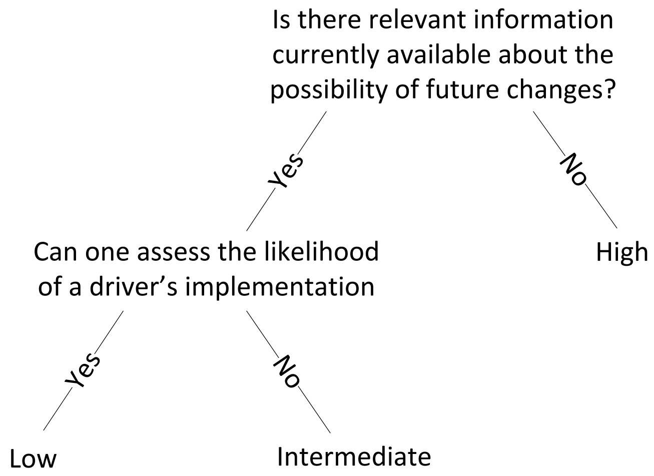

FIGURE 16 CLASSIFICATION SCHEME OF THE UNCERTAINTY OF DRIVERS

Elaborating on Table 10 further, the drivers of high and low impact will be commented upon – discussion on the intermediate classification follows right after. Obviously any type of regulatory intervention affects all users, hence a legal requirement for including source substitution systems in buildings and a water consumption quota are drivers of high impact. A potential technological breakthrough, unknown yet, could lead to better performing in-building water supply. Whether this impact will be high, intermediate or low, depends on the characteristics of the technology and the portion of the population that would be willing to adopt it. The latter could depend on many factors, such as the commercial availability of the technology, its performance, its costs and so forth. In order not to underestimate the potential effect of the driver, it is classified under the drivers of potentially high impact. A social trend by definition affects a large portion of the population, whereas labeling/certification regimes and subsidies can be an incentive for anyone to renew their equipment and/or install new piping system. Building refurbishment in the long term can be of concern for a large part of the city and it allows for both technology upgrade and installation upgrade. For these reasons, all previous drivers are classified as drivers of high impact. Financial drivers, such as the economic crisis, low energy consumption and low cost of purchase and installation/short payback period are classified as low impact drivers. The household budget for water is quite low, thus only businesses that consume large amounts of water are expected to be concerned with the financial benefits of reducing their water consumption. Energy efficient appliances, such as new washing machines or dish washers, will generally be bought if a new appliance is needed in the household (see the intermediate impact driver *life cycle of current appliances*); only a small portion of users would be willing to buy a new appliance purely because their energy consumption is low. Similarly, the low cost of purchase and installation or the short payback period of a new appliance or installation is not a high incentive if the life cycle of the previous equipment has not been completed or if the building is not about to be refurbished[16] (see also the intermediate and high impact drivers *life cycle of current appliances*, *life cycle of building installations*, *building refurbishment*). The better appearance of appliances seems to be a weak driver that could affect a small part of the users, unless it is accompanied by an extensive social

[16] A building may be refurbished even if the installations are not close to the end of their life cycle. For example a change of use of the building or spatial planning may require such an action.

interest due to branding or successful marketing. Even in the latter case, it seems unlikely that a large portion of the population could be influenced as there are financial anti-incentives for a user to invest in a new building technology if the old one is still functional.

The rest of the drivers are classified under *intermediate impact*, because their expected impact cannot be assessed neither as high nor as low. The increased environmental concerns, awareness of climate change and change in pricing regime may bring about water saving through all three types of consumption regime change, namely behavioural change, technology upgrade and installation upgrade. Thus, even if a relatively small portion of users is affected by these incentives, their impact cannot be considered low. The willingness of users to be self-sufficient seems to be quite an extreme case, nonetheless such an action signifies zero water consumption and not just a partial drop. It is a driver that could potentially affect all types of users and is, thus, classified under intermediate impact. Appliances of better performance in a number of characteristics may incentivize a non-negligible number of users to upgrade their equipment. Even though such innovative technologies are not yet part of the market, this driver expresses the possibility of a groundbreaking new development in housing appliances –this is the reason why it is also categorized as highly uncertain. The life cycles of building installations and current appliances may be of concern for a large part of existing buildings in the long term. However, since the life cycles do not coincide, they are considered drivers of intermediate impact and not high. The willingness of a company to brand their name and market their corporate image through water sustainability is expected to influence both the technology and the installations of the company's building(s), thus generating a quite high degree of water saving. Business users represent a portion of the consumers that have high average consumption, thus the *social image/brand* driver is considered of intermediate impact. Lastly, metering is expected to incentivize users to consumer less water and a considerable percentage of households in the area of Amsterdam are yet to be metered. Additionally, smart metering, that has not yet been implemented, could lead to additional water consumption decrease. For the previous reasons, metering is also classified as a driver of intermediate impact.

In terms of the uncertainty of the drivers of Table 10, the drivers of high and low uncertainty will be discussed –elaboration on the intermediate classification follows. Whether there will be a life style change in the Netherlands or a social trend that could affect a large part of the population towards adopting water saving attitudes and technologies cannot be yet predicted; no relevant was able to be found during the research. The occurrence of a life style change or a social trend for water saving is currently unpredictable, thus highly uncertain. Political decisions, not directly connected to scientific research, such as a new building code or other regulation that would introduce a legal requirement for additional water sources in buildings –other that the water supply system– are highly unpredictable and uncertain. Technological advances, even though rapid, are not predictable. It is not possible to foresee whether a technology that could affect in-building water supply will be developed, if it will be commercialized, or when such a breakthrough could take place. Thus, technological breakthrough is also characterized by high unpredictability and uncertainty. The extent to which the environmental concerns and climate change awareness of the residents of Amsterdam will become higher or whether they would be willing to engage in an effort to become self-sufficient are unpredictable. The technological developments and innovations are also beyond predictability, as is the evolution of an economic crisis or the occurrence of a new one, that could incentivize residents to cut down on household and business water budgets. In terms of low uncertainty drivers, a water consumption quota is rather unlikely due to the abundance of water resources that does not render water demand management measures necessary. Under the current knowledge about water resources availability in the area of Amsterdam and the value of water in the Netherlands, it is unlikely that a water consumption quota will be introduced. Additionally, if there would be a reason to think towards this direction, the drinking water companies would be aware of it early in advance. VEWIN, Association of Dutch Drinking Water Companies in the Netherlands, is in close contact with regulators in national and European level, as well as research institutes ("Profile Vewin," 2013). Thus, if it becomes a necessity to introduce water consumption quota, the drinking water companies will be aware. Similarly, other water demand management measures such as subsidization for new water saving equipment –which will be incentivized by governmental parties (Waternet, 2013)– and a change in pricing regime that would promote water saving are not of interest and are rather unlikely. Thus, they are categorized under the drivers of low uncertainty. Data about metering is available to Waternet, i.e. all unmetered buildings are known. Of these buildings, some cannot be metered due to technical difficulties, as commented upon on §4.1, whereas the rest are expected to be metered in the future when the opportunity is given. Thus, one part of the unmetered buildings is unlikely to be meters and the rest are likely to be metered, rendering metering a quite predictable driver.

The remaining drivers are classified under *intermediate uncertainty*, because their predictability could not be considered high (low uncertainty) or low (high uncertainty). Labeling/certification regimes, that could increase the value of property and form as an incentive for the upgrade of building equipment, have already been introduced by the European Commission (*Establishing the ecological criteria for the award of the Community Eco-label for Buildings*, n.d.). However, water conservation is only one amongst many criteria, it is hence uncertain to what extend building owners will include water conservation to their own goals. Building refurbishment is quite likely to take place in the long term in a large part of the urban grid, however as materials are becoming increasingly durable and one cannot estimate what percentage of buildings will indeed be refurbished; there is still some uncertainty entailed. Nonetheless, information exists about the state of current buildings (Fire department of Amsterdam-Amstelland, 2012), fact which could provide an insight to Waternet as to which areas are more likely to experience refurbishment in the next few decades. Another source of information is the long-term spatial plans of the city of Amsterdam (Waternet, 2012, 2013) that details the development projects of the municipality for the next few decades (Van der Beuken et al., 2011). Similarly, the life cycle of building installations is a driver for which some information is available, yet again one cannot assess a likelihood in terms of installing new piping equipment that would generate a water consumption decrease. Information about the life cycle of appliances could also become available, for example through statistical analysis of the data of the suppliers. The willingness of people to replace current equipment with more water aware designs, however, entails uncertainty. The incentive of branding and developing a sustainable corporate image is limited to business customers, fact which somehow limits the uncertainty of this factor. On the other hand, one can predict if businesses will be incentivized indeed to engage in water saving for this purpose. Thus, the driver is classified as one of intermediate uncertainty. The uncertainty of financial incentives, such as low energy consumption, low cost of purchase/installation and short payback time, is somehow limited by the available information in terms of the life cycle of equipment, that can be another parameter in the decision of buying new one. Nonetheless, one cannot assess if this driver will indeed incentivize users to renew their appliances of piping installations. In terms of the improved appearance of appliances, it would be extreme to assume that a groundbreaking development will take place in the design of housing appliances. Nonetheless, such a possibility exists and it is not possible to assess which amount of the population will be influenced. One should keep in mind that branding of equipment can lead to unpredictable turns in the market, thus the driver is classified *under intermediate uncertainty*.

The drivers that are expected to have a significant impact on the water demand and, simultaneously, whose occurance is hard to predict are considered the most critical for Waternet, as they can bring about abrupt or unexpected changes. On the 3x3 table, this translates into the 2x2 top-left sub-table (high and intermediate uncertainty, high and intermediate impact). Additionally, interesting drivers for Waternet are the drivers of high impact and low uncertainty: even though predictable, the water company will need to keep following the relevant developments in order to foresee the demand decrease that could be induced and try to take it into account in their long term planning.

These drivers can help formulate educated scenarios about the future. To facilitate understanding towards this end, an example is elaborated in the Appendix of Chapter 5 (see *Elaborating on an example driver*).The example concerns the driver of *building refurbishment* and is based on published data and a number of assumptions that are clearly stated.

In order to understand how the critical drivers and the drivers of interest can realize in the Metropolitan Area of Amsterdam, it is significant to examine which actions of stakeholders can *incentivize* changes or express that they *have been incentivized* to adopt changes. Such a discussion and analysis is included in the following paragraph.

5.2. Main stakeholders that can adopt or incentivize water saving and generate a significant water consumption reduction in an aggregate or localized level

The drivers of water demand reduction have been previously classified according to their uncertainty and impact (see Table 10) and the multi-stakeholder environment of the problem in hand has been briefly commented upon on Chapter 4 (see Table 8 and Table 9). A more elaborate investigation of the actors of the building sector in the Metropolitan Area of Amsterdam, such as the number and detailed ownership extent of housing corporations, the large contractors, the main suppliers and so on, can generate additional insight on the stakeholders, however it falls out of scope of the current research. The focus lies on the actions that can generate a drop in demand and that can *incentivize* change or denote the *adoption* of change.

Table 11 includes actions that can generate a drop in demand and which have been identified by investigating which actors can *incentivize* change or can *be incentivized* to adopt change. The classified drivers of water saving were the starting point for this investigation. These actions, classified by the impact and uncertainty of the equivalent driver –as previously discussed– are presented *per stakeholder*. Thus, the table supplies an overview of the most influential stakeholders in terms of water saving and water demand and the main actions that could signify water demand drop.

TABLE 11 CLASSIFICATION OF ACTOR ACTIONS THAT CAN GENERATE RETAIL WATER CONSUMPTION DECREASE

Actor	High uncertainty	Intermediate uncertainty	Low uncertainty
Housing Corporations	Adopt a water-saving social trend in building design	Install rain-water harvesting systems [17] and water saving appliances during building refurbishments	Inform Waternet when refurbishing in order to install water meters (i.e. decide to renew building installations)
	Engage in environmentally cautious behaviour	Seek to acquire water saving labels or certifications (if available & increasing property value)	Install water-saving appliances or building installations because of lower energy consumption
	Attempt to decrease (collective) water invoicing by changing appliances	Invest in company branding by adopting water saving measures	Install new appliances because of better appearance
	Install water saving appliances because of better performance (e.g. faster operation, less noise)	Install water saving appliances when conventional ones are close to completing their life cycle	
		Install water saving technologies because of low costs/short payback time	
Large business consumers	Adopt a water-saving social trend in building design	Install rain-water harvesting systems and water saving appliances during building refurbishments	
		Seek to acquire water saving labels or certifications (if available & increasing property value)	
		Invest in company branding by adopting water saving measures	
Chain businesses	Adopt a water-saving social trend in building design	Invest in company branding by adopting water saving measures	

Impact of driver (*see §5.1*):	High impact	Intermediate impact	Low impact

[17] Or greywater systems if regulation allows it or if the law is circumvented.

Actor	High uncertainty	Intermediate uncertainty	Low uncertainty
Media[18] (or unidentified influential entity)	Drive a social trend for water saving		
	Raise concern for environmental and climate changing issues		
Unidentified actor(s)		Expand and promote labelling/certification regime and value for real estate	
Regulator		Introduce labelling/certification for building water consumption	Introduce quota for water consumption
			Change water pricing regime
			Render metering installations obligatory
Public Authority (unidentified)			Introduce subsidization for water saving appliances and installations
Suppliers	Promote new breakthrough technologies, once available	Supply water saving appliances of high performance (e.g. faster operation, decreased noise)	Supply water saving appliances and rainwater harvesting installations that consume less energy
	Promote water saving appliances	Supply water saving appliances and rainwater harvesting installations that generate less maintenance costs	Supply low-cost water saving appliances
			Supply water saving appliances with better appearance than the present (non-water saving) appliances
Contractors			Install and maintain rainwater harvesting installations effectively and with low costs

Impact of driver (*see §5.1*):	High impact	Intermediate impact	Low impact

[18] Media are meant here in the traditional term. However, taking into account the extensive use of social media, the same role of promoting water saving could be undertaken by any influential person or organization. This could be intentional or coincidental. In the latter case, the role is more similar to that of an early adopter who sets a paradigm for the rest of the consumers (see elaboration within main text).

Housing corporations, large business consumers and chain business, such as franchise chains, are stakeholders that generate a high level of water demand drop, aggregate and localized, and form also as “early adopters” that can lead to a more extensive adoption of water saving in the system. These actors are characterized by high consumption and/or extensive building ownership in the Metropolitan area of Amsterdam. If they adopt a water saving attitude or install water aware technologies in their properties, the *aggregate impact* on water consumption drop will be quite large, as compared to individual households or small businesses. For this reason, the actions of specific households and of small businesses are not considered of such high interest and are not included in Table 11. Additionally, the owned properties of these single owners tend to be large and in the vicinity of each other. Thus, water consumption drop in these cases may affect a single block or neighbourhood as a *concentrated demand drop*, fact which indicates that certain parts of the system are *more prone* to water demand reduction than others. As indicated in Chapter 3 and discussed in §3.1, water quality in the distribution system depends on the local characteristics of the flow. Thus, such concentrated alterations are expected to have a higher impact in the water quality than, for example, dispersed “sources” of water saving.

The same actors, namely housing corporations, large business consumers and chain business, can bring about water demand reduction through a number of actions characterized by high, intermediate or low uncertainty. Stemming from the drivers of water saving previously discussed, a housing corporation can adopt a potential water-saving social trend or engage in environmentally cautious behaviour and implement a number of changes in their buildings in order to achieve low water consumption under these incentives. During building refurbishments or when housing appliances need renewal, a housing corporation may decide to install water aware equipment and generate a significantly lower water consumption in large buildings and multiple sites. Seeking to increase the value of their properties through labelling regimes or company branding could be incentives towards this direction. Such actions could take place regardless of the state (life cycle phase) of the appliances and of the installations of a building, however a (nearly) complete life cycle could constitute a window of opportunity. More actions of housing corporations that can generate an impact on water consumption are included in the table and follow similar reasoning. Comparable is the case of large business consumers and chain businesses, that can adopt water saving, install water aware equipment and generate an impact on the aggregate and localized level of water demand. So far, the reasoning suggests that housing corporations, large business consumers and chain businesses can affect water demand through the reduction of their own, currently large, consumption.

One should also keep in mind that the large water consumption of the aforementioned actors may indicate that they have an interest to engage to water saving behaviours *sooner* than the average consumer. Their financial power, as compared to individual owners, is also larger and may allow for investing in large scale projects or even pilot projects. Large consumers may become early adopters of water aware technologies and set a paradigm of successful cases for others to follow. This possibility should be investigated further upon by other principles than Policy Analysis, more specialized to commercial and niche markets.

On the other hand, the media and persons or organizations of influence to the public, possible actors that can promote labelling and increase its market value, regulators and public authorities (EU, national, local), suppliers and contractors are stakeholders whose own consumption is of no great interest, however they have the means to promote incentives towards water saving. Respectively, they can incentivize parts of the population to engage in water saving by driving a social trend and increasing environmental awareness, expanding labelling regimes and increasing their value in the real estate market, introducing water management measures and new regulations, subsidizing water aware design and installations, promoting certain types of technologies and equipment and offering low cost and high quality services. As already discussed in §3.3 and §5.1, the above incentives are related to social, regulatory and financial drivers that can promote water demand reduction and installation of water efficient building equipment.

The investigation of the reasons behind each of these actions falls outside of the scope of the present research. However, *after* identifying the actions (or *strategies*) that could promote water saving to a high degree, it becomes significant to also understand why an actor would engage in such a behaviour. Investigation of the objectives, interests and alternative strategies of each actor becomes now relevant for Waternet to form its own strategies and, possibly, initialize negotiations. Clearly, in order to attempt taking such a pathway, firstly the objectives of the company itself need to be agreed upon, clarified and adopted by the whole organization.

After identifying the *drivers of water saving* –and the more specific *actions towards water saving*– as the *causes* of water demand drop, the *effects* that such a reduction could bring about to the system are investigated.

5.3. Effects of water demand reduction for the water supply system of the Metropolitan Area of Amsterdam

System effects by the reduction of water demand for the water supply system of Waternet are investigated through decomposing the system into subsystems that are analysed further.

The main characteristics and structure of the water supply system of the Metropolitan Area of Amsterdam were presented at the beginning of Chapter 4. The system is here decomposed into three subsystems, namely the *Pre-treatment system (PT)*, the *Drinking water treatment system (DT)* and the *Distribution system (DS)*. Each subsystem is characterized by a certain function that is achieved through a number of operations (see Figure 17). The criteria for the decomposition are dictated by the focus on water demand and by the practical necessity of exploring subsystems that can be managed and operated individually. Thus, taking into account both institutional and technical features of the water supply system, the criteria are the following:

- the exit of each subsystem is characterized by at least one sale type, i.e. industrial, wholesale or retail (see also Figure 14 of Chapter 4)
- each subsystem can be *physically disconnected* from the rest through shutting down one or more valves
- each subsystem has a *single owner* or a *single operator*.

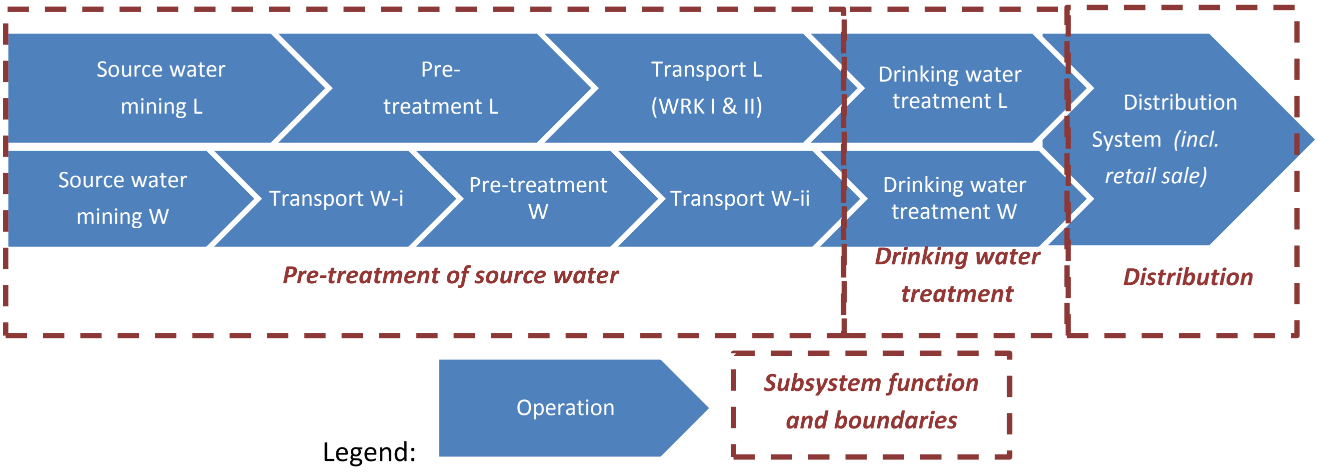

FIGURE 17 DECOMPOSITION OF THE WATER SUPPLY SYSTEM OF THE METROPOLITAN AREA OF AMSTERDAM – L: *LEIDUIN CHAIN* AND W: *WEESPERKARSPEL CHAIN*

In order to simplify the presentation of the susbsystems' analysis below a *code* is assigned to each subsystem (see Table 12). Additional information on the physical entities, functions and boundaries of the subsystems are supplied in the Appendix (see Table A - 3).

TABLE 12 CODING OF SUBSYSTEMS

Subsystem	Code
Pre-treatment – Leiduin Chain	PT-L
Pre-treatment – Weesperkarspel Chain	PT-W
Drinking water treatment – Leiduin Chain	DT-L
Drinking water treatment – Weesperkarspel Chain	DT-W
Distribution	DS

Figure 18 schematically presents the flow of water characteristics along the subsystems. As is indicated in the graph, the quantity of the produced water is based on forecasted values regarding the expected water demand and remains the same along the chain as there is no significant loss of mass[19]. The indicated delays justify the presence of reservoirs (and lakes) that regulate the differences in production rate and consumption rate. The amount of water processed in upstream subsystems defines the available quantity to be treated further and to be distributed downstream, thus it also determines whether water delivery can be conducted in a continuous way. On the other hand, water quality is altered significantly along the chain of production. As indicated by the thin dashed (blue) lines, quality upstream does not affect the quality downstream. This assumption is supported by the provisions of the water company to control the output water quality. An exception is the quality of water in the distribution system. The input quality determines also the output quality to the tap of consumers. The latter results from the fact that no residual disinfectants are used and from the inability to fully monitor and control water quality within distribution systems (see also 3.1).

[19] With an exception of water losses that in terms of this research can be considered negligible

In the Appendix (see Figure A - 2 until Figure A - 6) the conceptualization of each subsystem into input-output is included. The internal architecture of each one provides additional insight on the relations presented on Figure 18. The diagrams have been constructed to be relatively simple, however understanding requires some basic knowledge of water supply system design and operation, thus the corresponding analysis is not part of the main body of the report. The information of Chapter 4 is useful for understanding the conceptualization of the pre-treatment system and the drinking water system, whereas understanding of the input-output diagram of the distribution system may require tracing back to the publications included in Chapter 2.

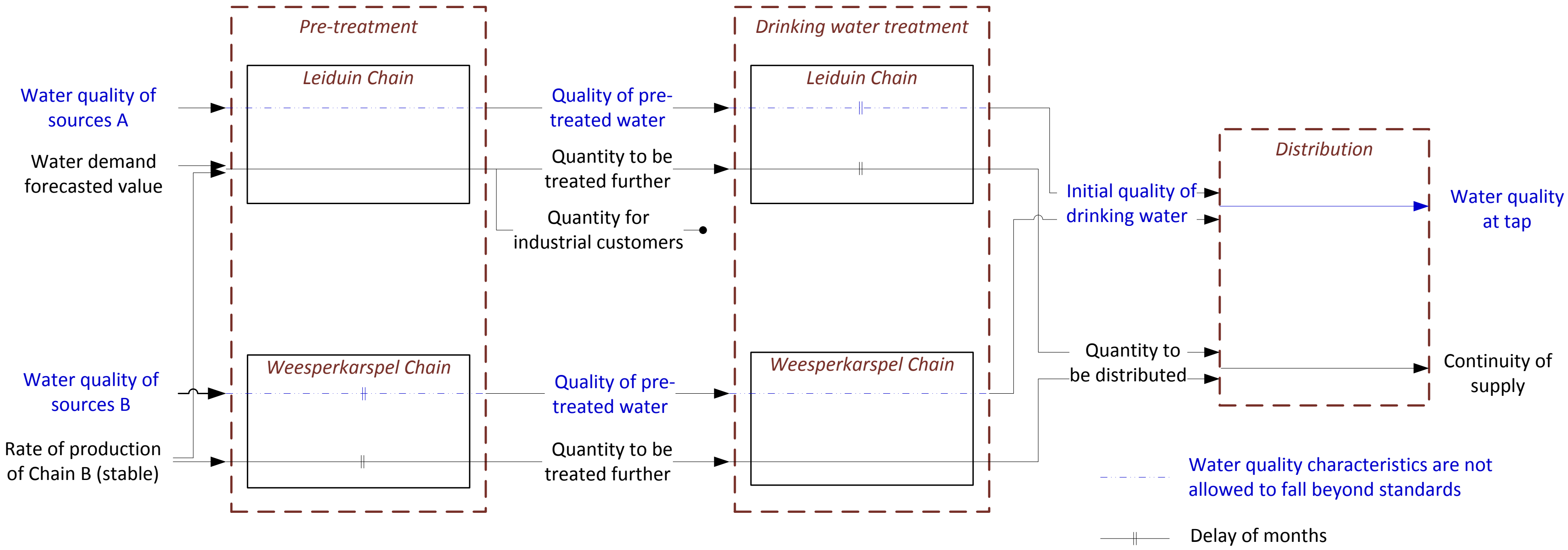

FIGURE 18 MAIN INPUT INFORMATION AND MONITORED OUTPUTS IN TERMS OF WATER QUALITY AND WATER QUANTITY ALONG THE SUBSYSTEMS OF THE WATER SUPPLY SYSTEM OF THE METROPOLITAN AREA OF AMSTERDAM

In order to identify the potential effects of a water consumption decrease by retail consumers, the performance indicators that will be investigated need to be chosen. As discussed in Chapter 3, the assessment of the performance of water supply systems is rather complex. For the assessment of the effects the objectives that were presented in Chapter 3 are used (see Table 2). Additionally, the quantity of produced water is included in the table of effects. Even though the quantity itself is not a measure of the performance of the system, it is a common monitored output that can characterize the degree of utilization of the system. It is, thus, of interest.

Table 13 supplies an overview of the effects of decreased retail consumption for the whole of the water supply system. The distribution seems to be most vulnerable to a decrease in demand, whereas the effects at the pre-treatment system and the drinking water treatment system are largely unknown. Under the current operational rules, the performance of the Weesperkarspel chain (*DT-W*, *PT-W*) will not change as production rates are maintained stable and all demand fluctuations are regulated through the Leiduin chain (*DT-L*, *PT-L*). For the needs of the analysis the assumption is made that this choice will not be altered. Changing the production regime is a strategic choice that cannot be a priori assessed. For example, adjusting the production rate of the Weesperkarspel chain as a response to a decreased water consumption is possible, however it falls amongst a large number of technically feasible alternatives that need to be examined further (see also §4.3). As a simplification, only the current production regime is discussed (stable rate for the Weesperkarspel chain and fluctuating rates for the Leiduin chain) and the effects are examined on the system *as is*.

In terms of the distribution system, *quality degradation* and *income decrease* are expected. Quality degradation may also cause, as second order effects, supply disruptions, increased needs for cleaning and, subsequently, increased costs. The potential of quality degradation beyond health standards, signifies that the level of safety can be affected. The reader should keep in mind that the effects on the distribution system may be *localized*, as sedimentation and residence time depend largely on the local conditions of water flow. In that manner, areas of the system that are currently characterized by long residence times and low velocities (see Chapter 3 and Figure A - 2 of the Appendix) are more vulnerable to the effects of demand reduction. The latter are characterized by water quality that is below average, thus further degradation is more risky.

The drinking water treatment system, as discussed already, should be examined separately for the two chains of production. The operations of *Chain L* (Leiduin) will be adjusted to the decreased consumption rates. The effects on the treatment efficiency and on the output water quality are currently unknown, however, in principle, provisions will be taken to ensure that the output drinking water quality adheres to the health standards set by Waternet[20]. The above may signify an effect on the marginal cost of production[21], that is also

[20] These standards are higher than the standards set by regulation.
[21] The marginal cost is meant as the total cost (fixed cost plus variable cost) of producing an additional unit (m^3) of water

unknown. The operations of *Chain W* (Weesperkarspel) will not be affected, as the operational rules dictate that production rate is stable.

Lastly, the effects on the pre-treatment system are similar to the above. In a potential water consumption drop, the rates of processes of Chain L will need to be adjusted. It is known that the processes are adaptable to some degree, however it is unknown whether the output water quality could be affected and to what extent, depending also on the magnitude of the retail water consumption decrease. A potential, unknown, second order effect could be a change in the willingness of industrial customers to remain customers with the current invoicing regime if pre-treated water quality degrades. The effect of lower production rates to the marginal cost of production is also unknown. Chain W will not be affected under the current operational rules.

As can be understood from the above, the objectives of *high water quality* and *good financial balance* (see also Table 2 of Chapter 3) will incur the primary effects of a potential drop in demand. Hence, they will constitute the initiating point for investigating alternatives in paragraph §5.4.

TABLE 13 SUMMARY OF EFFECTS OF A WATER DEMAND DECREASE TO THE WATER SUPPLY SYSTEM PER SUBSYSTEM ASSUMING THAT (I) PRESENT OPERATIONAL RULES AND (II) WATER QUALITY STANDARDS WILL NOT BE ALTERED

Subsystems / Objectives	DS	DT-L	DT-W	PT-L	PT-W
Water quality	**Quality degradation due to increased residence time and lower velocities**	**Unknown effect on the treatment efficiency**	*Stable rate of production*	**Unknown effect on the treatment efficiency**	*Stable rate of production*
Quality of service	Continuity of supply may be affected by more frequent discolouration incidents or pipe cleaning [*Second order effect*]	N/A	N/A	N/A	N/A
Financial balance (income, costs)	**Decrease of retail income**	**Unknown effect on the marginal cost of production**	*Stable rate of production*	**Unknown effect on industrial sale income [*Second order effect*]**	*Stable rate of production*
	Cost of operations and maintenance may increase (pipe cleaning/flushing) [*Second order effect*]			**Unknown effect on the marginal cost of production**	
Safety	Could be affected if water quality degrades beyond health standards	Water quality adheres always to health standards	*Stable rate of production*	N/A	N/A
Quantity of water at the outlet tanks	N/A	**Production rate is adjusted to the consumption rate.**	*Stable rate of production*	**Production rate is adjusted to the consumption rate.**	*Stable rate of production*

Certain effect | Possible effect | **Unknown effect** | *No effect*

5.4. Mitigation of potential effects

Potential alternatives to mitigate the effects identified in §5.3 are investigated below. The reader should keep in mind that the investigation is *static*, based on the whole water supply system and attempts to clarify available options/tactics for Waternet. The proposed alternatives stem from (i) the system analysis and (ii) the operations and design elements presented in Chapter 3.

Due to the multiple objectives of water supply systems, alternatives that could mitigate the effect on one objective, are expected to generate impacts to at least one other objective. Thus, the potential impacts of each alternative are also presented. The convention of colours used in Chapter 2[22] is adopted in these schemes (see Figure 19). The links between the effects/system status and the alternative decisions indicate existing options. The links to alternative actions indicate existing options (dashed line) or required action (solid line). The links to impacts denote possible effects (dashed line) or certain effect (solid line) (see also Figure 19).

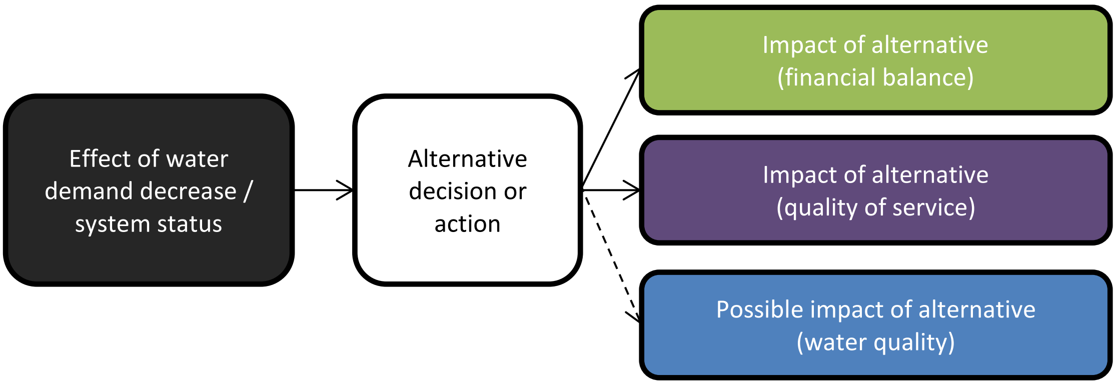

FIGURE 19 SCHEME OF THE INVESTIGATION OF ALTERNATIVE MITIGATING ACTIONS AND THEIR IMPACTS PER EFFECT OF WATER DEMAND DECREASE

The main first order effect on the distribution system is water quality degradation, however this does not necessarily signify water quality below the standards set by Waternet or by regulation. Even though cleaning programs are expected to be more frequent, if water quality is still above the company's standards there would be no need to alter current practices. After all, as velocities and residence times vary throughout the distribution system, so does the water quality which is not uniform. If the quality is monitored (or simulated) to be below Waternet's standards, then the effort could be made to maintain these standards by extensive cleaning programs, resizing the system or improving water treatment, i.e. improve the input quality of water in the distribution system. However, since the standards of Waternet are higher than the standards set by regulation, there is also an option of lowering the standards of water quality in the distribution system. Lowering the standards of drinking water is, at first sight, not a very favourable alternative. However it should not be excluded from the analysis even if it seems somewhat unrealistic. It is a feasible option and there are margins to lower the quality within health and legal standards. If the financial sustainability of the company is jeopardized, the alternative of lowering the initial water quality could be brought to the table, if nothing else, as a

[22] Blue: drinking water quality, Purple: Quality of service, Green: Financial balance

negotiation tool in discussions with other stakeholders. The above are schematically presented in Figure 20.

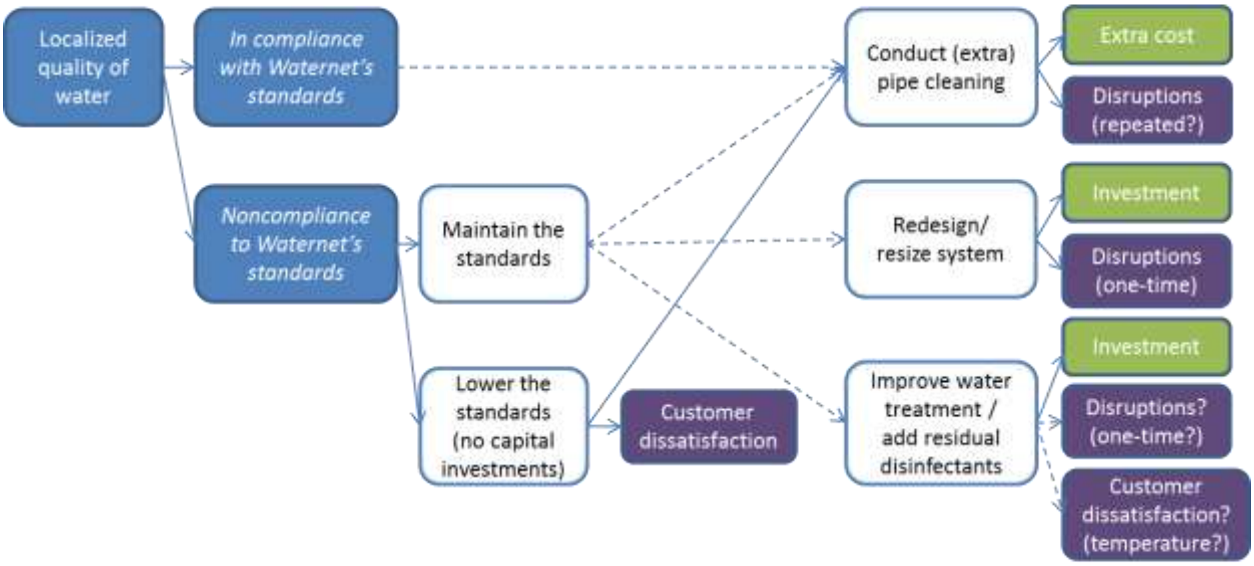

FIGURE 20 MITIGATING ALTERNATIVES FOR THE EFFECTS OF WATER CONSUMPTION REDUCTION ON THE DISTRIBUTION SYSTEM: WATER QUALITY

The case of the output drinking water quality from the drinking water treatment system case is more complicated, because the effects of water consumption reduction are largely unknown. Nonetheless, the same principles as previously apply and the standards of Waternet could be maintained or lowered. Water quality may be above or below the standards set by Waternet. If quality is above standards, in principle, the water company does not need to take any action. However, it is possible that the marginal cost of production will be higher due to the decreased output quantity. In this case, the alternative of redesigning the system to a new, lower capacity should be examined. In case of output water quality below standards, i.e. in case of the treatment efficiency being affected by the decreased rates of water production, standards could be maintained or lowered to the degree that regulation allows it. In order to maintain the standards, the system could be redesigned in terms of its capacity, it could be operated at higher rates of production than consumption or the water treatment processes themselves could be upgraded. Producing more water than demanded, i.e. *operating with excess water*, sounds quite unrealistic. However, when exploring alternatives it should be taken into account. For example, it may be possible to sell this additional water to non-retail customers. Even more, the ability/capacity to produce water that is not demanded may be used as a negotiation tool to maintain the size of the system whilst engaging in a collaboration regime with other drinking water companies (whose water resources are not as abundant as those of Waternet). Maintaining water standards in case of lowered treatment efficiency comes at a cost, whether this signifies a need for investment or the decision to produce water that will be sold cheaply or not at all[23]. As an alternative, lowering standards will generate an impact

[23] The excess drinking water could be sold to en-gros customers or even industrial customers, regardless of its high quality. This will still generate an income loss when compared to the present situation, as the tariffs for en-gros and industrial sale are lower than the retail value.

on the final quality of the distribution system –fact which could in turn lead to other secondary impacts– and on the level of satisfaction of customers. As discussed before, this is not a preferred solution but it is feasible within health and legal standards. The above are summarized in Figure 21.

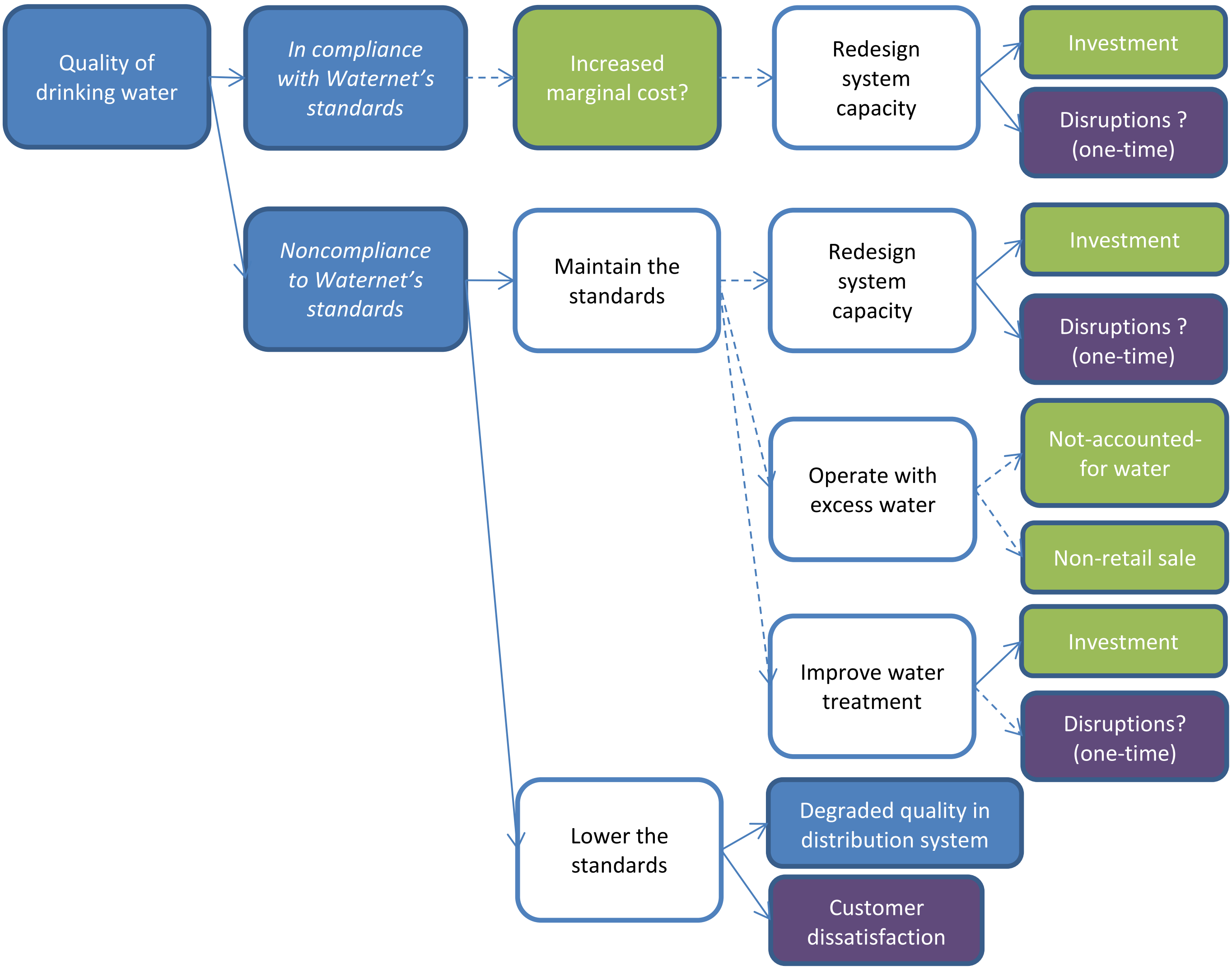

FIGURE 21 MITIGATING ALTERNATIVES FOR THE EFFECTS OF WATER CONSUMPTION REDUCTION ON THE DRINKING WATER TREATMENT SYSTEM: WATER QUALITY

Equivalent to the above are the alternatives in terms of the effects on the pre-treated water quality. As discussed previously, the effects of the demand reduction in this case are largely unknown, because of the qualitative approach of the research (see §5.4). Even though it is technically possible to adhere to the standards of pre-treated water quality, for example through adjusting the rates of production, the effect on the efficiency of the treatment is unknown. In a qualitative manner, the nature of negative effects has been identified and, thus, alternatives can be identified as well. What is interesting is that, additionally to the alternatives of the drinking water treatment system, the output water quality of the pre-treatment system can be improved also through improving the initial quality of water. This signifies that when investigating a redesign for the system, not only the processes but also the possible sources of water should be considered in order to opt for a beneficial alternative. The previous are schematically presented in Figure 22.

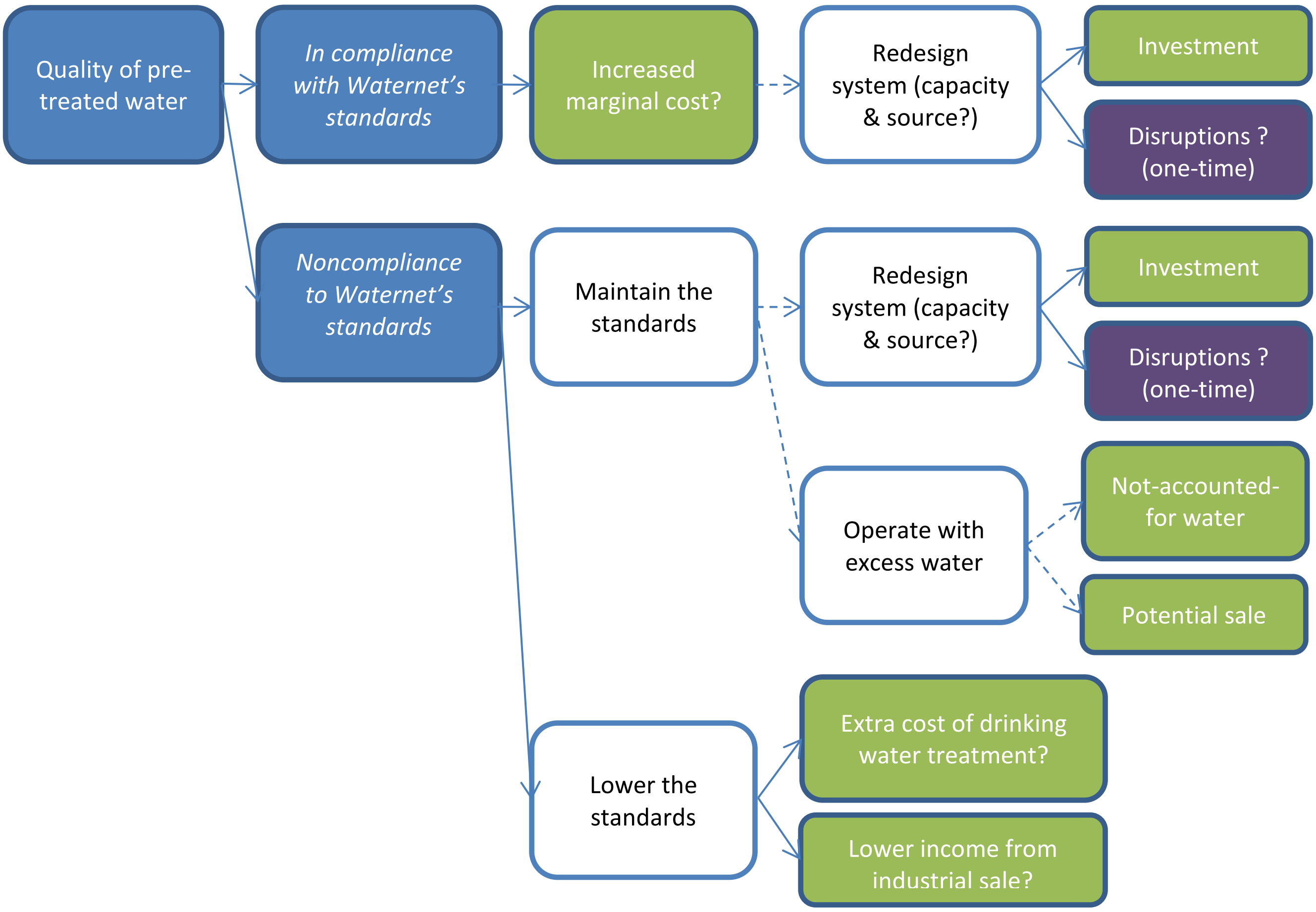

FIGURE 22 MITIGATING ALTERNATIVES FOR THE EFFECTS OF WATER CONSUMPTION REDUCTION ON THE PRE-TREATMENT SYSTEM: WATER QUALITY

Besides water quality, a significant effect of water demand drop is the reduction of the company's retail income. Additionally, increased costs are expected, at least in the operations of the distribution system. Even though the financial effects on the whole water supply system have not yet been investigated, alternatives to improve the financial balance of Waternet can be identified. In essence, the alternatives attempt to increase the income of Waternet under a decreased retail consumption regime or to decrease costs. The latter is both a matter of production regimes and of the organizational management of the company. Further investigation of these alternatives falls out of the scope of the current research, but is considered essential as Waternet is delivering drinking water under a full-cost recovery regime. The alternatives are presented in Figure 23

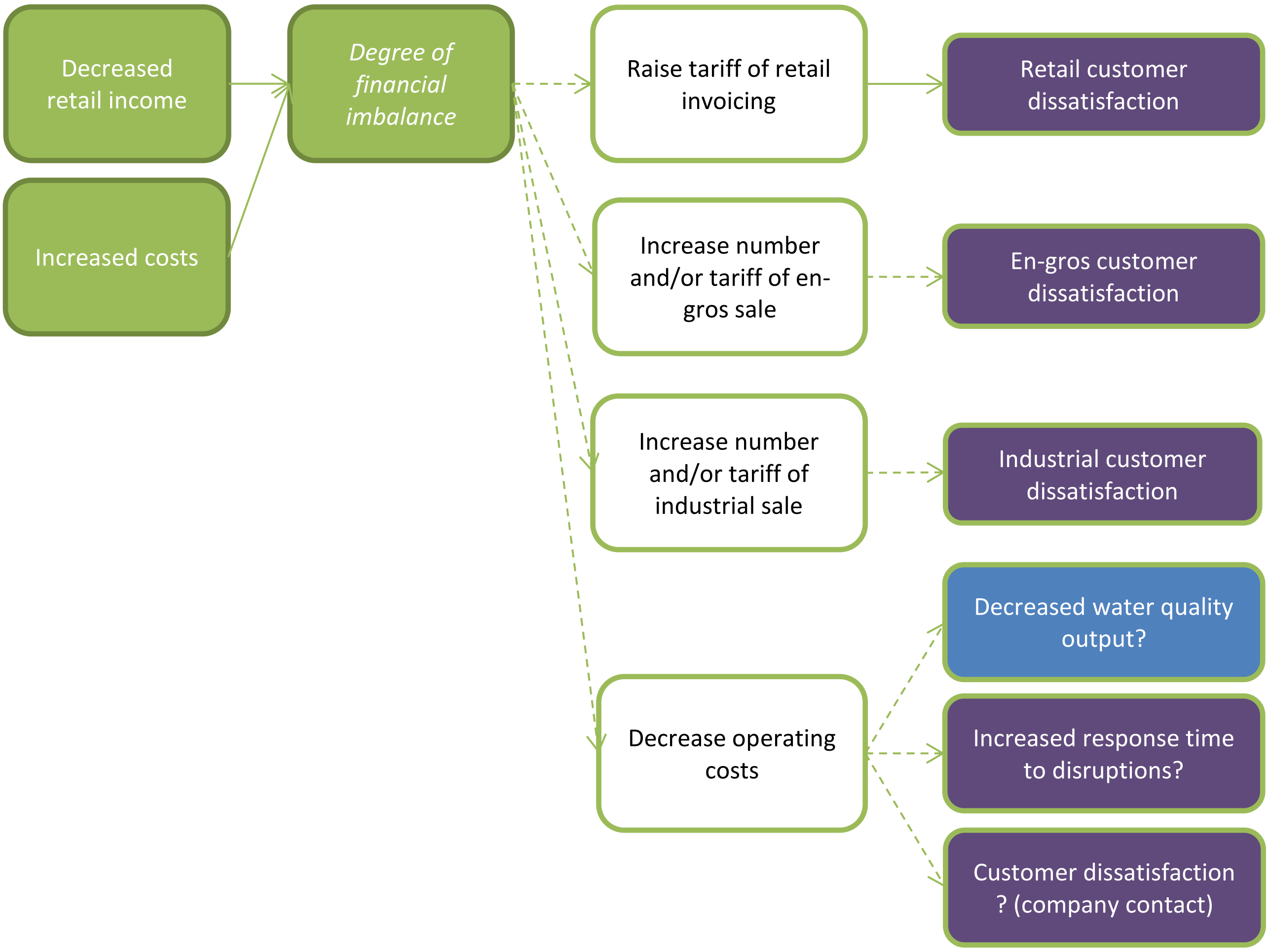

FIGURE 23 MITIGATING ALTERNATIVES FOR THE EFFECTS OF WATER CONSUMPTION REDUCTION ON THE DISTRIBUTION SYSTEM: INCOME DECREASE

Chapter 6. Conclusions, recommendations, reflection

This chapter contains (i) the conclusions drawn by this research, (ii) recommendations for Waternet, and (iii) reflection on the research methodologies, the project, and its limitations.

6.1. Conclusions

The analysis has indicated that the problem in hand is uncertain in a number of ways. The impact and realization of the identified driving forces of water demand drop, the current and future condition of the system that cannot be monitored fully, the potential effects to the system, all entail uncertainty. However, the initial problem and issues have become more clear and the following conclusions have been drawn. The presentation of the conclusions is conducted per research question, as those are described and elaborated upon in Chapter 1.

Q1. *How is the water supply system functioning?*

The purpose of this research question has been to understand the system in order to find a suitable way to decompose it and, subsequently, identify the potential effects by a reduction in retail water demand.

The system decomposition indicates that different subsystems are characterized by a different demand: the pre-treatment system satisfies the whole water demand, namely industrial, en-gros and retail, the drinking water system satisfies the drinking water demand, namely en-gros and retail, and the distribution system satisfies only the retail demand (see Chapter 4). The *aggregate water demand* of each is of interest in order to estimate how their performance will be affected. Thus, the effects of water demand reduction by the retail customers needs to be examined separately for each subsystem.

The investigation of the water supply system also indicated that each point of sale to industrial and en-gros customers is serviced with water that is produced along one of the chains of production, i.e. either the Leiduin chain or the Weesperkarspel chain. It also indicated that the Weesperkarspel chain is characterized by a stable rate of production and that fluctuations are regulated through the Leiduin chain (see Chapter 4). These facts indicate that the chains of production are characterized by different production regimes and need to be examined separately. At the same time, though, it is technically possible for this distinction between the chains to alter. Thus, when addressing a long-term plan for the water supply system, the chains of production should also be examined in combination. The latter has not been conducted in this thesis, as the goal has been to examine the system *as is* (see also §5.3).

Another point of importance is that the quality of water in the distribution system is not uniform (see Chapter 3). Localized water consumption regimes and pipe size affect the hydraulic conditions and subsequently the water quality. Consequently, in terms of the distribution system, not only the *aggregate water demand* but also the *localized water demand* is of interest. Oversized pipes are related to diminished water quality and are largely present due to fire hydrant provision (see Chapter 3). When addressing a long term plan it is relevant to investigate whether these hydrants can be removed and under which conditions. Hydrant removal enables downsizing of the pipes of the distribution system and can generate benefits such as better water quality and lower costs.

Q2. ***Which are the drivers of water saving, which are the main relevant stakeholders and which areas are more prone to such changes?***

The purpose of the second research question has been to identify the nature, the uncertainty and the impact of the driving forces of water saving in the Metropolitan Area of Amsterdam.

The literature indicates that water saving is prominent in water scarce areas. However, driving forces of water saving in an area of abundant water resources can also be identified (see §3.3). The classification of these drivers according to their uncertainty and impact indicates that there are drivers of more significant uncertainty and/or impact than the rest (see §5.1). The latter constitute the *critical drivers* and the *drivers of interest* where Waternet should focus their attention in terms of future developments.

Customers are characterized by different levels of water consumption and urban stakeholders, in a more general sense, are characterized by different ways in which they can affect the dynamics of urban renewal (see Chapter 4). By adopting drivers of water saving –as a large customer– or by promoting drivers of water saving and incentivizing a large portion of retail customers to adopt them –as an influential stakeholder–, there are actors that can cause significant *water demand reduction at localized or aggregate level*. Thus, identifying such actors and their potential actions towards this direction is important (see §5.2). Even more, possible *clustering* of the properties of large consumers –think of an area of large hotels or of an area where one single housing corporation operates– indicates that there may be areas more prone to (abrupt) water demand reduction than others.

Q3. ***How could the performance of the water supply system be affected by a drop in demand and how could the adverse effects be mitigated?***

This question is of high significance for Waternet. The potential effects of a water demand reduction by retail consumers have not yet been investigated, neither have the alternatives for maintaining a high performing system by mitigating the negative effects.

The objectives and performance indicators of a water supply system (see Chapter 3) constitute the criteria for assessing the effects, whereas the existing mechanisms and operations for ensuring high performance constitute the main source of the alternative mitigating techniques (see Chapter 3). Resulting from Q1, the effects of the water supply system are examined *per subsystem* and *per production chain*. The investigation of the effects on the system *as is* indicates that there are still significant uncertainties and knowledge gaps of how it would respond to a potential water demand drop. A significant reason explaining this fact is the uncertainty in terms of the future aggregate water demand for each of the subsystems[24]. It also becomes clear than certain areas of the

[24] An exception to this uncertainty, under the current analysis, is the assumption that the Weesperkarspel chain will continue operating under stable production rates, hence a "stable water demand".

distribution system may be more vulnerable to the effects of localized water demand reduction (see §5.3). Hence, the investigation of *localized water demand reduction* is also of interest. The mitigating alternatives, presented per effect, are accompanied by their subsequent impacts. The multi-objective investigation indicates that seeking to satisfy one objective may have negative impacts on others.

Q4. ***How could Waternet use the knowledge acquired from the above research to address future challenges?***

This question aims to combine and synthesize the acquired and generated knowledge into actions that could facilitate the work being conducted for the Long Term Vision for the water supply system (see §4.3).

The identified critical drivers of water saving and actions that could promote water consumption reduction, as discussed in Q2, can supply the base for the formulation of educated scenarios (see Chapter 2) of both aggregate and localized values of retail water consumption reduction (see §5.1, §5.2 and the *Elaborating on an example driver* part of the Appendix of Chapter 5). Under these quantitative scenarios of water demand, Waternet can explore the possible future performance of the current system. At the same time, these scenarios can be utilized to examine the robustness of the, already developed, redesign alternatives for the pre-treatment and drinking water treatment subsystems that are included in the existing parts of the Long Term Vision.

The identification of specific critical actions that can promote water saving allows for proactive intervention by Waternet, as long as they remain alert and informed about the short- and long-term strategies of critical stakeholders. Estimating the timing and the extent of water demand drop in a multi-stakeholder environment is not easy. Attempting to monitor certain actions of certain stakeholders seems more feasible, however the timing cannot be anticipated unless the company is in communication with these actors. Monitoring stakeholders' *strategies* towards these actions can be more beneficial than monitoring the actions themselves. Such an effort to be informed about the future plans of relevant stakeholders will facilitate the reduction of future uncertainties, the formulation of long-term plans and their adaptation, as needed.

6.2. Recommendations

The thesis research was conducted to contribute to the long term planning of Waternet in terms of their water supply system. The recommendations attempt to address issues in a strategic long-term manner, taking into account Waternet as a water cycle company and not purely as a water supplier.

(1) Taking into account the uncertainty in terms of future water demand and its potential effects, Waternet should invest in acquiring more knowledge about the current system and its dynamics.

- Water quality is the primary concern and the effort should be made to acquire better information about the condition of the system, for example through increasing monitoring locations or by promoting further scientific research towards this end.

- Engaging stakeholders constitutes a way to gain knowledge of the system, understand its dynamics and investigate plausible futures. To name a few, the equipment trends in the market, the willingness of civilians to adopt water saving attitudes and the long term strategies of the critical stakeholders are pieces of information that Waternet could acquire by investing in communication and negotiating strategies.
- The additional insight into the system can facilitate Waternet to prepare for the future. Blocking developments may not be possible or even desirable –as it could harm Waternet's public corporate image. However, by developing bonds and forming alliances, the company can gain additional knowledge and adapt their planning or even affect the developments. For example, the company may delay or accelerate the maintenance or replacement of their assets according to the anticipated actions of other stakeholders or they may seek to convince other stakeholders to coordinate their actions to Waternet's asset management plans. Identifying the objectives, the interests and the alternative strategies of relevant stakeholders can supply useful information for negotiations towards this end. The supply of a public good itself may be a negotiation tool for the water utility.
- Improved information about the dynamics of water quality in the distribution system can also form as a negotiating tool, as commented above.

(2) Utilizing the driving forces and the stakeholder actions that were identified through this research, Waternet should formulate educated scenarios of aggregate and localized future water reduction and assess them under different alternatives. This process should be supplementary to the existing water demand forecasting methods.

- As indicated in Q3, the effects of water demand reduction are not be clear. Further scientific research may be necessary, however simulation and technical-economic studies should supply at least some rough estimation of quantitative effects.
- The qualitative investigation of effects per subsystem conducted in this thesis can constitute an example of how the results could be summarized and communicated amongst colleagues and departments (see §5.3).
- The current asset management practices can be assessed under different scenarios of localized and aggregate water demand drop.
- The existing redesign alternatives for the pre-treatment and drinking water treatment, included in the Long term Visions for the water

supply system (Hofman et al., 2008; Rook et al., 2011), can be assessed under different scenarios of aggregate demand drop.

- The possibility of a water demand increase should not be neglected.
- The tactics suggested in this thesis as mitigating alternatives can also be incorporated in the above studies.

(3) Waternet needs to set a goal in terms of water saving. Do they wish to prevent, follow or lead such developments? Is water saving a threat or an opportunity?

- In order to reach such a decision, technical-economic studies may be necessary.
- Being a water cycle visionary company, Waternet should address this issue in the context of a long-term integrated urban water management vision. The aforementioned technical-economic studies should not be limited to the water supply system.
- The fact that fire hydrant provision is becoming less necessary should be taken into account.

The above conclusions and recommendations can be synthesized into an indicative *plan of action* for Waternet towards the continuation of the Long Term Vision for their water supply system. The generic steps of such a plan of action, initialized by the thesis research, would be (I) *attempt to reduce uncertainty* in terms of future water demand –both aggregate and localized–, (II) *explore the future*, for example through contextual scenarios, (III) examine *alternatives*, (IV) formulate further the *Long-Term Vision* and (V) *adapt the Long-Term Vision* as new information becomes available that could affect steps (I)-(IV). During this iterative process it is important to also examine how the Long-Term Vision of the water supply system corresponds to the objectives of Waternet as a company, as well as how the Vision fits the long term planning of the other departments. This will be possible after some understanding has been established on the quantitative dimension of the issue.

Step I can be elaborated further. Through the current thesis research, uncertainty has been reduced to a certain extent. However, following the conclusions and the discussion above, uncertainty about aggregate and localized future water demand can be further reduced (at least) in the following way(s):

(A) Aggregate water demand

- Identify the housing corporations, the large business consumers and the chain consumers, as well as their water consumption levels. If some of the chain customers demonstrate relatively low consumption levels, they may not be of high interest. Also identify the main suppliers and contractors in the Metropolitan Area of Amsterdam and, possibly, the media that are most influential to the public.
- Examine if any of the above actors have already engaged in environmentally friendly behaviour or actions that could promote water saving.

- Engage in some type of communication with these actors, starting from those that show an environmentally friendly (or water saving) attitude. The purpose is to gradually build relationships of trust with these actors and acquire information about developments as described previously in this Chapter.
- Similar should be the attitude towards regulators.
- Explore iteratively whether the above actors plan to adopt water saving attitudes or install water saving equipment.

(B) Localized water demand

- Investigate the current urban fabric and identify the location of large business consumers and housing corporations; particularly examine if there are areas where clustering is observed or where a large number of buildings belongs to any single owner.
- Examine if any of the above actors have already engaged in environmentally friendly or water saving actions.
- As previously, engage in some type of communication with these actors, starting from those that show an environmentally friendly (or water saving) attitude. The purpose is to gradually build trustful relationships and acquire information about on-going and future developments.
- As previously, explore iteratively the strategic plans of these actors in terms of adopting water saving attitudes or installing water saving equipment.

Step II, namely future exploration, entails many uncertainties. In terms of this thesis, the focus lies solely on water demand reduction by retail customers. Hence, only water demand reduction in building level is discussed. When exploring the future of the water supply system, however, the potential of increase needs to be taken into account, as well as other relevant factors (see also §4.3).

Some alternatives for Step III are already available. In this thesis simple mitigating techniques are suggested, whereas the existing parts of the Long Term Vision include a number of technically feasible alternative designs for the whole water supply system. As already commented upon, investigating the performance of each alternative under different scenarios formulated in Step II may prove to be a challenging task.

Step IV, formulating the Long-Term Vision further, would stem from an assessment of the outcomes of Step III. However, for a system of multiple objectives that is characterized by a number of uncertainties, the assessment of alternatives is not straightforward.

Step V is meant to express the iterative nature of long-term planning. As new insights become available, the Long-Term Vision should be re-examined and adapted as needed.

Waternet can already start addressing Steps I and II. Insightful knowledge can be acquired regarding the urban actors that can cause water demand reduction, whereas the drivers of water saving constitute a readily available tool for formulating scenarios. Once scenarios have been formulated, the subsequent Steps can be addressed as well. It is quite selfevident that Steps I, II and III may be revised independently as new knowledge becomes available. What is significant to realize is that Step IV may also be revised independently. For example, a change in the value system of the problem owner (or of the customers) may change the preferred alternative or the preferred combination of alternatives.

6.3.Reflection

Conducting the current research through Policy Analysis methodologies has been decided since the beginning, taking into account the complexity and uncertainty of the problem that needed to be addressed. However, concluding on the exact techniques that would be used has been iterative and challenging. As new data and insights were becoming available, the initially chosen techniques needed to be adjusted in order to generate better outcomes. The applied techniques have proven beneficial for the analysis and understanding of the problem, as well as for generating useful products for the problem owner.

However, the final product of the research could have been improved in a number of ways, mostly by including the insights of a larger number of people through intermediate meetings, brainstorming sessions and additional interviews. For example, a brainstorming session could have been conducted with employees from different departments of Waternet. By bringing people together, different perceptions in terms of future water saving could have been revealed and discussed. Group thinking would also have facilitated the creative collaboration between departments. A brainstorming session could also have been conducted with students and professors of various principles at the Delft University of Technology. Fresh and deviated ideas may have been generated about how and by whom water saving could be promoted or largely adopted. Additionally, it would have been insightful to conduct an interview with at least one representative of a housing corporation. Unfortunately, the above have not been possible, mostly due to constrains of time and resources.

Due to time limitations, the research has not advanced further into extensive quantitative figures. The scope has been largely qualitative and only a few quantitative figures and examples have been supplied. However, further research could have been conducted to facilitate the long term planning of Waternet. For example, instead of supplying only one detailed example of formulating educated scenarios, a larger number of contextual scenarios could have been generated to estimate possible futures in terms of aggregated water demand, including demographical developments. Additionally, data and information about urban ownership regimes –who are the major building owners and which are their areas of operation?– and customer consumption could have been collected and edited. This data could have formed a useful tool in formulating realistic future scenarios about localized water demand in the form of a map. For example, the map could have included the location of housing corporations' buildings, the largest consumers, the presence and extent of chain businesses, and others. All this data exists, at least, at the invoicing records of Waternet, it is however not readily available. Last but not least, a full stakeholder analysis could have been conducted. The effort would have been made to determine or assess the number, extend and long-term strategies of housing corporations, the interests of large businesses and their environmental profile, the main suppliers and their future aspirations, and so on. The effort was made to retrieve information and data that would enable some of the aforementioned types of elaboration. However, the acquired documentation was not sufficient for proceeding towards this direction without significantly extending the duration of research.

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Appendices

Appendix of Chapter 1

TABLE A - 1 LOCATION OF THE ANSWERS TO THE RESEARCH QUESTIONS IN THE TEXT

Sub-question	Answered in
Q1a	Chapter 4 (introductory part)
Q1b	Chapter 4 (introductory part , p. 37, "*Waternet, that operates… (World Water Council, n.d.)*") §4.1
Q1c	§4.3
Q1d	§5.3 (until Figure 18)
Q1e	Chapter 3 (introductory part, p. 19 "*The design and operation…*" until Figure 4) Figure A - 2 until Figure A - 6
Q2a	Chapter 3 (introductory part, p.22 "*A significant parameter…*" until Table 3)
Q2b	§3.2 (p. 29 "*Water consuming technologies…*" until the end of the subchapter) §3.3
Q2c	§5.1
Q2d	§4.2 §5.2
Q2e	§5.2 (p. 52 "*Housing corporations, large business… "sources" of water saving*")
Q3a	Chapter 3 ("*Understanding the objectives… (see Table A-1).*" Table A-1
Q3b	§3.1
Q3c	§5.3 (p.56 "*In order to identify…*" until Table 13)
Q3d	§5.3 (p.56 "*In terms of the distribution system… is more risky.*")
Q3e	§5.4
Q4	Chapter 6

Appendix of Chapter 2

TABLE A - 2 OBJECTIVES AND INDICATIVE OPERATIONALIZED CRITERIA FOR THE PERFORMANCE ASSESSMENT OF A WATER SUPPLY SYSTEM

Goals/objectives	*Low level objectives: operationalized criterion (-a)*
High drinking water quality	High level of compliance to health and aesthetic standards: Sample water quality measurements, type and number of customer complaints, (average) residence time estimations, simulations
HIgh quality of service	High level of continuity of supply: CML planned, CML unplanned
	Sufficient pressure: sample measurements, type and number of customer complaints
	High customer satisfaction: customer complaints, survey results, (above) sample measurements
Good financial balance	Low operating costs: budgeted and accounted values (of fixed and variable costs)
	Low capital costs: accounted values
	High income: budgeted and accounted values
High level of safety	High level of compliance to water quality health standards: see above
	Low level of distrurbance to other activities: Failure rate of assets, recorded incidents

Appendix of Chapter 4

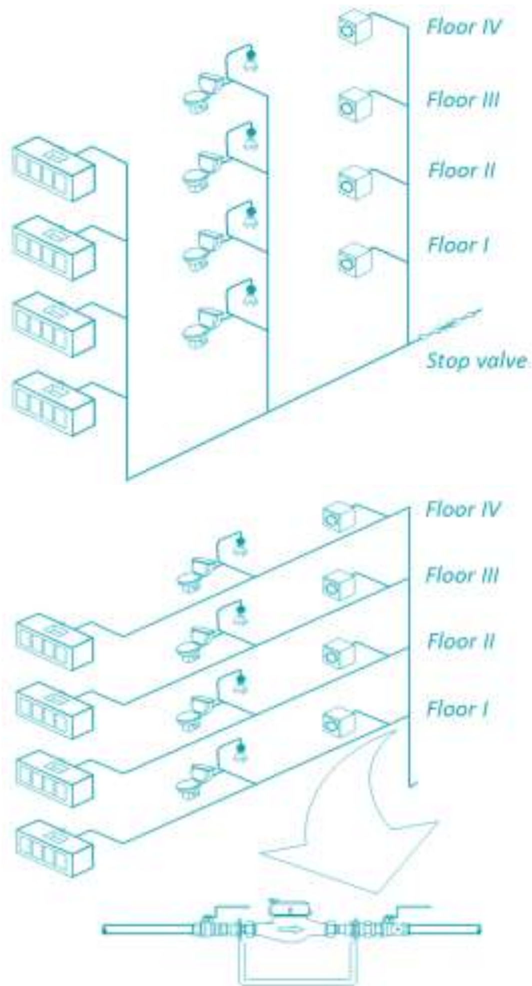

FIGURE A - 1 PIPING INSTALLATIONS IN NON-METERED AND METERED APARTMENT BLOCK (GEMEENTE AMSTERDAM, 2003) [*EDITED AND TRANSLATED FROM DUTCH*]

Appendix of Chapter 5

Elaborating on an example driver

In order to better understand how the outcomes of the previous analysis can by utilized, an example driver of water saving is elaborated upon (see also *§5.1*). The problem owner was interested in the *building refurbishment according to the spatial planning of the city of Amsterdam* and in a rough indication of water demand reduction that could stem from such developments. The effort is made to indicate how such an estimation could be conducted, with inevitable assumptions, and emphasize on the how the multiactor perspective can prove beneficial.

Spatial planning developments for the City of Amsterdam were published in 2011 and are describing the City's spatial planning until 2040 (Van der Beuken et al., 2011). According to the planning, three phases are distinguished: *2010-2020*, *2020-2030* and *2030+* (Van der Beuken et al., 2011; "Kaarten Structuurvisie Amsterdam 2040 - Gemeente Amsterdam," 2013). Amongst other developments, city densification and city renewal schemes will take place in the next few decades. Both are relevant for Waternet, however the focus here lies on the drop of demand. In terms of spatial planning, water demand reduction could stem from the *urban renewal* where it is accompanied by extensive building refurbishments and investments in water saving by building owners.

The city renewal is scheduled for the decade 2010-2020 and should be completed in the decade 2020-2030 ("Kaarten Structuurvisie Amsterdam 2040 - Gemeente Amsterdam," 2013). The main areas under re-construction are situated in the city districts – *stadsdelen*– of North Amsterdam (Noord), Zuidoost and Nieuw-West. The most extensive urban renewal scheme is taking place in Nieuw-West (Van der Beuken et al., 2011) and is also the case for which quantitative publicly available information is more extensive[25]. Thus, the urban renewal scheme in Nieuw-West will form as the focus of this example. The other cases could be worked upon similarly.

The urban renewal planning of Nieuw-West started in 2001 and regards the demolishment of about 13.000 houses and the construction of about 24.500 houses by 2015, with an unidentified number of plans being abandoned between 2005 and 2007 mostly due to financial reasons (Gemeente Amsterdam - Stadsdeel Nieuw-West, 2010; "Nieuw West: Richting Parkstad 2015 - Amsterdam, NL," 2013, "Nieuw-West en Richting Parkstad 2015," 2013). The progress of the planned works in terms of construction and reconstruction has had significant delays by 2010, ranging from 36-60% of the set targets for the same year, whereas by 2010, 4.200 houses were demolished (Gemeente Amsterdam - Stadsdeel Nieuw-West, 2010). When the urban renewal plans are finalized,

[25] Through a brief research, no useful quantitative information was found regarding building refurbishments in the city district of Noord. Regarding the city district of Zuidoost, information is limited to the area of Bijlmer specifically: an unspecified number of housing buildings had been demolished until 2011, out of which 60% had been reconstructed and 40% was yet to be rebuilt (Van der Beuken et al., 2011).

the area is expected to host 16% more people than previously (Gemeente Amsterdam - Stadsdeel Nieuw-West, 2010).

The rate of continuation of the renewal scheme is unclear. In order to make a quantitative assessment of the number of houses that will be refurbished, a number of assumptions need to be made. The latter could be further clarified by Waternet through communication with relevant stakeholders to obtain more detailed and up-to-date information. The following assumptions are made for the needs of this example:

- Since 2010 no more buildings are to be demolished.
- The buildings that were to be demolished according to the initial planning (the remaining number of houses is 8.800) will be refurbished in order to deliver larger apartments.
- The desired average future size of the apartments if $85m^2$ with the average size at the beginning of the urban renewal being $65m^2$ (Gemeente Amsterdam - Stadsdeel Nieuw-West, 2010). Thus, the old 8.800 houses will become about 6.730 houses of larger sizes.
- The average number of inhabitants per household will remain stable. This assumption is supported by the fact that local residents are expected to keep living in the same area (Gemeente Amsterdam - Stadsdeel Nieuw-West, 2010)[26] and maintain their former family/housemate lifestyle.
- According to the above, each of the refurbished *buildings* is expected to have a decreased consumption of about 25% due to a smaller number of (larger) houses with the same average number of inhabitants per household. When estimating an aggregate value of water demand reduction this information is *not* relevant, as the local residents will be relocated within the same area (Gemeente Amsterdam - Stadsdeel Nieuw-West, 2010). This information, however, is interesting when investigating the localized water demand reduction at street or neighbourhood level[27].
- The reference year is terms of average water consumption is 2012.
- The average water consumption per inhabitant in Nieuw-West is the same as the average water consumption per inhabitant in the Metropolitan Area of Amsterdam[28].

The following data is also relevant:

- Total number of households (summation of metered and unmetered household water connections): 61.948[29] (Waternet, n.d.)
- Total population in Nieuw-West: 139.886[30] (Hylkema et al., 2012).

[26] This figure is assumed to be the average value of 5 years (2008-2012) as indicated in (Hylkema et al., 2012). The generated value is equal to 2,26 persons per household, but is not used in calculations here.

[27] As will be indicated later on, information of such detail was not able to be retrieved for the needs of this example.

[28] The 2012 value is 136L/inhabitant/day (Waternet, n.d.), but is not used in calculations here.

[29] According to the statistical data of the City of Amsterdam, there were 61.010 houses in Nieuw-West in 2012 (Hylkema et al., 2012). However, Waternet’s figure is considered more accurate for the needs of this estimation.

No reference has yet been made to the possibility of a water demand reduction being induced during the refurbishments. To explore this future possibility, scenarios need to be formulated. In contextual scenario analysis, the explored future values of driving forces need to be at least *two*, in order to indicate that some uncertainty is involved (De Haan and De Heer, 2012). There is no maximum number of scenarios, however the more scenarios one makes, "the more effort it [will] take[…] to do a full analysis of all alternatives" afterwards (De Haan and De Heer, 2012, p.114) (see also Chapter 2, §6.1 and §6.2 on how scenarios can be a tool to assess the performance of different alterantives). Usually, the effort is made to combine the driving forces into scenarios that describe a future environment in quite general terms (Enserink et al., 2010); for example if economy is a driving force for change then a scenario of "economy in crisis" or "economic welfare" could be formulated and possibly specified through other, more detailed, qualitative or quantitative parameters. In a similar way, when addressing the issue of water saving, affected by a large number of driving forces, it may be beneficial to formulate a small number of generic scenarios. For example, if one would decide to formulate only two scenarios, one scenario could be "no particular efforts towards water saving" and a second one could be "intense water saving by all drivers". These two scenarios could give a simple indication of the extreme values of water saving. The more information there is about the future and the strategic planning of other stakeholders, the more educated and realistic these scenarios will be (see also §5.2). In this example, the possibility of water saving during building refurbishment is addressed and follows the above reasoning; the two explorative scenarios are formulated.

For the urban renewal scheme in Nieuw-West, the *zero scenario* is formulated as "no particular effort towards water demand during building refurbishments". This does *not* necessarily signify that water consumption will *not drop at all* during building refurbishment. As all scenarios should be realistic to a certain degree, changes that are, anyway, occurring without seeking water saving should be taken into account. For example, about 25% percent of the households in Nieuw-West do not have water meters (Waternet, n.d.). If the refurbishment to be conducted in the next few decades, according to the spatial plan of the City of Amsterdam, concerns such buildings and if meters are installed during this process, a small drop in water demand should be anticipated (see also §3.3). For the needs of this example, this scenario will not be elaborated further as detailed information about this occurrence has not been retrieved.

A roughly estimated but educated value for the "intense water saving" scenario is generated below. The assumption is made here that *all households* will be designed and equipped with a water saving attitude to supply a rather extreme value. According to §3.2 rainwater harvesting systems for toilet flush can reduce water consumption by 29%, whereas upgrading of equipment and appliances can induce a further reduction of 26%. In total, household consumption could drop by 55%. Taking into account that 8.800 households out of the existing 61.948 will be refurbished (about 14%), the global water decrease in the area of Nieuw-West would be about 7,8%. As commented earlier, the

[30] This number actually results in an accurate figure for the *Average Number of Inhabitants per Household* (= *Total Population / Number of Households*)

fact that the number of houses per building will be decreased, does not need to be taken into account in this estimation of the aggregate water demand reduction. It would be interesting, however, to investigate the exact location of these buildings in order to make estimations about the localized drop in demand. In combination, it would be interesting to examine the location of the new buildings (that will accommodate the 25% of the current population[31]). Even though the spatial planning schemes indicate four areas under urban renewal in Nieuw-West (Van der Beuken et al., 2011), the exact location of the 8.800 houses that were to be demolished is not clear (Gemeente Amsterdam - Stadsdeel Nieuw-West, 2010; "Nieuw-West en Richting Parkstad 2015," 2013). Thus, this example does not contain any further elaboration on the localized demand reduction. It should also be noted that this "extreme" value of water saving in all buildings that are yet to be refurbished in Nieuw-West amounts to about 1% of water demand reduction in the distribution system.

This value can become more realistic by further research into existing information, by improving the assumptions and by monitoring developments. For example, an estimation of the capacity for rainwater harvesting (available area and volume for harvesting and storage of rainwater) in combination with the precipitation regime in Amsterdam will give an indication of the extent to which rainwater harvesting systems can replace drinking water for toilet flushing. Assumptions can be improved by retrieving more accurate and up-to-date figures about available appliances in the Dutch market and about the current and future phases of the urban renewal. Monitoring future developments can not only indicate whether the existing plans are being realized or not, but also ensure that new plans will not remain unknown to the company. Long-term communication with relevant stakeholders can supply information towards this end (see also §5.2, §6.1 and §6.2).

References of elaborated example

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[31] Due to the reduction of the number of houses from 8.800 to 6.730

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TABLE A - 3 MAIN CHARACTERISTICS OF THE SUBSYSTEMS OF THE WATER SUPPLY SYSTEM OF THE METROPOLITAN AREA OF AMSTERDAM

Subsystem code	Main physical entities	Main provisions and back-up systems	Functions	Points of physical boundary
PT-L	Lek Canal and Nieuwegein underground acquifer abstraction facilities, Cornelis Biemond Pre-treatment Plant, WRK (I and II) transport pipes	Double source. Triple transport pipes.	Abstraction, pre-treatment, transport	Source abstraction point, output point of WRK pipes (to DT-A), check valves of industrial customers
PT-W	Bethunepolder and ARK abstraction facilities, transport pipes to Loenderveen, artificial lake at Loenderveen, Pre-treatment Plant at Loenderveen, transport pipe to Weesperkarspel	Double source. Double transport pipe to Weesperkarspel.	Abstraction, pre-treatment, transport	Source abstraction points, inlet to the Weesperkarspel raw water distribution tanks.
DT-L	Amsterdam Water supply Dunes (AWD), Leiduin Treatment Plant, Drinking water reservoirs	Possibility to bypass AWD in case of failure. Multiple storage.	Treatment, storage	Output point of WRK pipes, inlets to distribution system (storage reservoirs)
DT-W	Weesperkarspel Treatment Plant, Drinking water reservoirs	Double storage.	Treatment, storage	Weesperkarspel raw water distribution tanks, inlets to distribution system (storage reservoirs)
DS	Low pressure pumps, Transport pipes, High pressure pumps, Distribution pipes, Multiple valves	Multiple pumps.	Transport, distribution	Storage reservoirs, check valves of retail customers

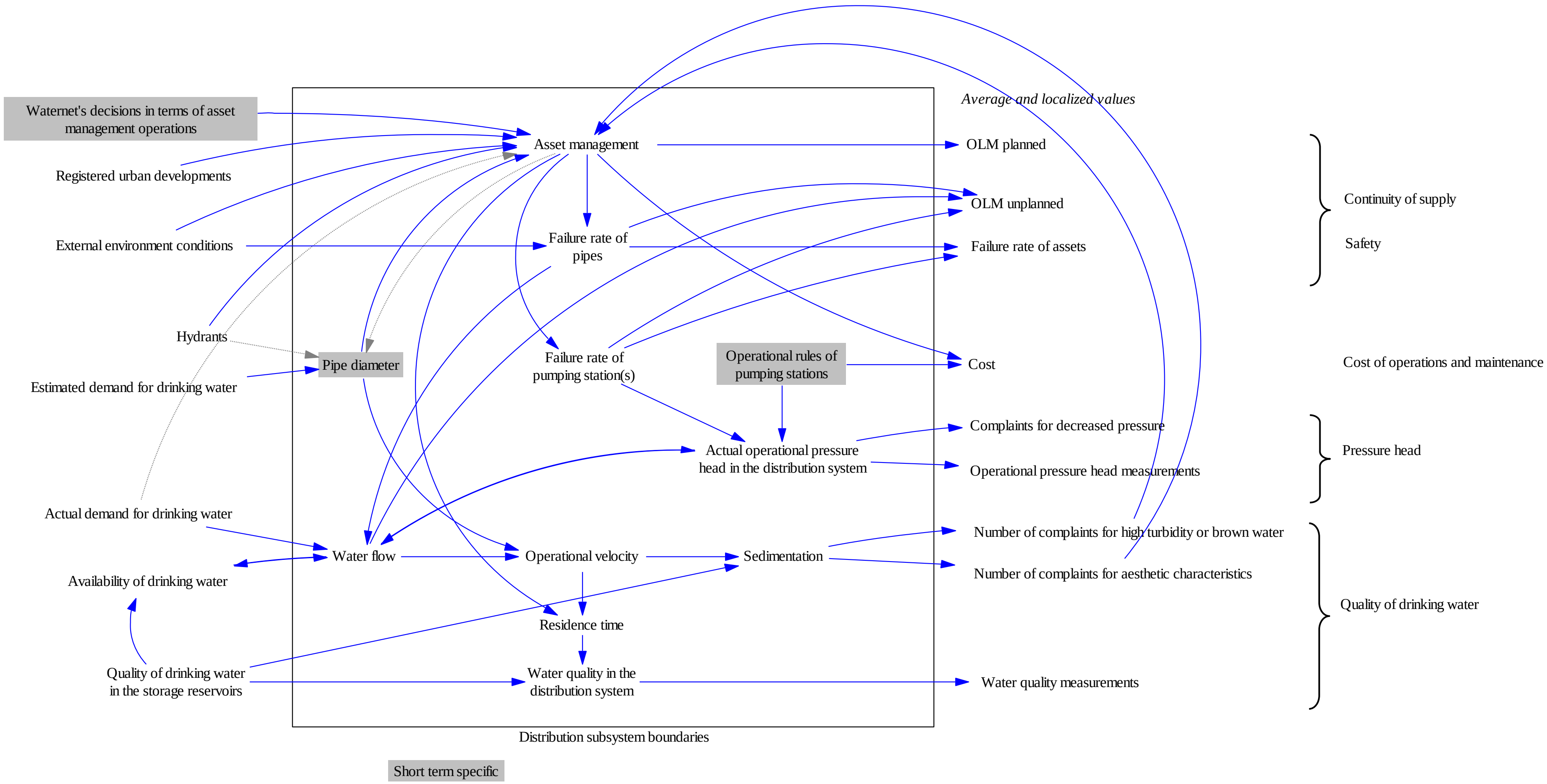

FIGURE A - 2 CONCEPTUALIZATION OF THE DISTRIBUTION SYSTEM (DS): MAIN INPUTS AND MONITORED OUTPUTS

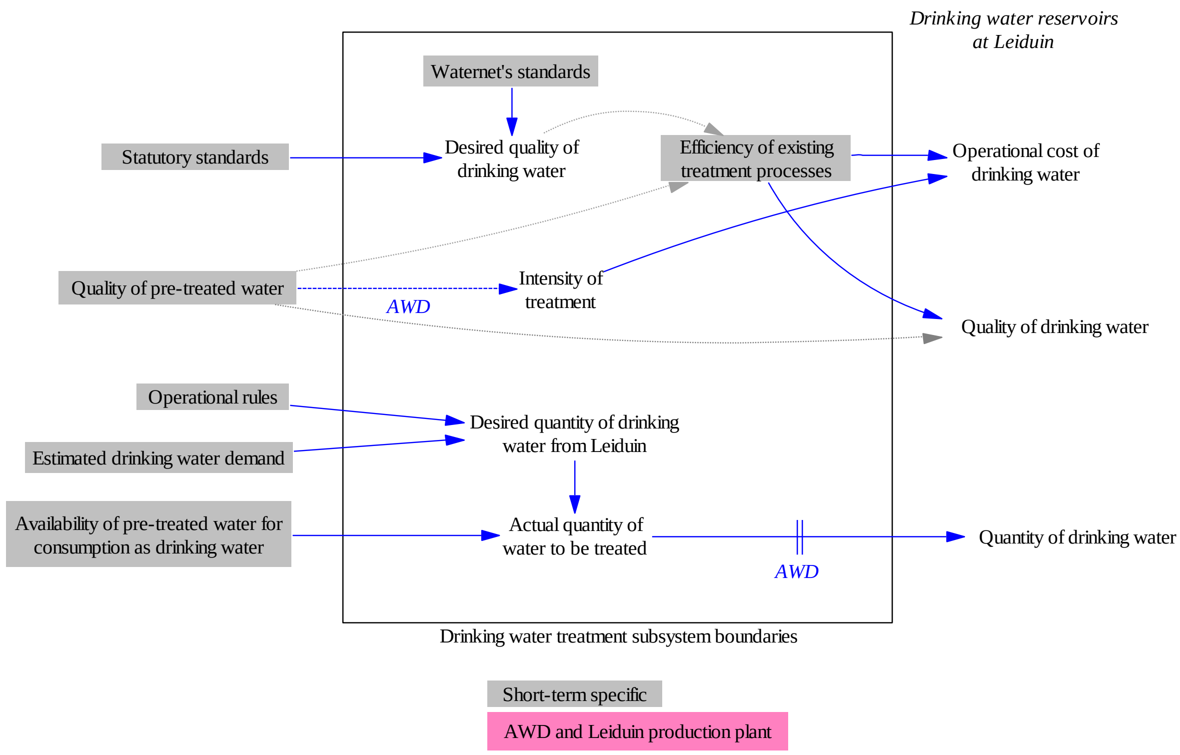

FIGURE A - 3 FIGURE 24 CONCEPTUALIZATION OF THE DRINKING WATER TREATMENT SYSTEM OF THE *LEIDUIN CHAIN* (DT-L): MAIN INPUTS AND MONITORED OUTPUTS

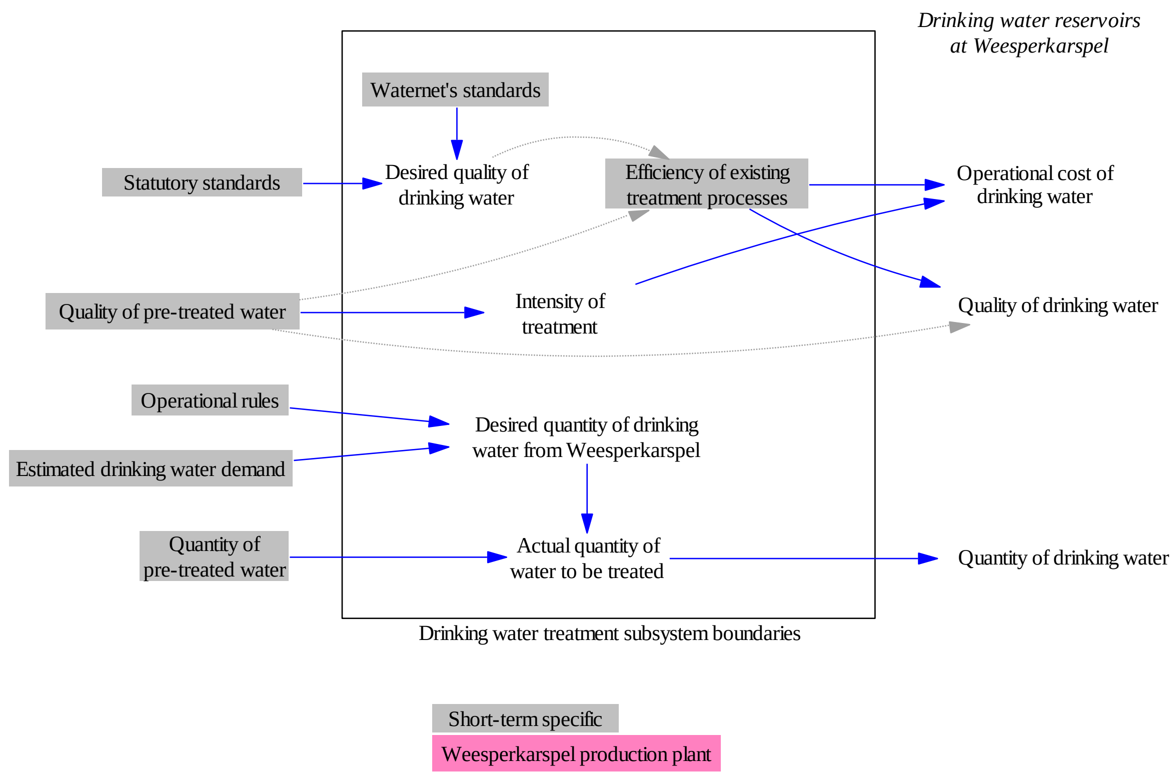

FIGURE A - 4 FIGURE 25 CONCEPTUALIZATION OF THE DRINKING WATER TREATMENT SYSTEM OF THE *WEESPERKARSPEL CHAIN* (DT-W): MAIN INPUTS AND MONITORED OUTPUTS

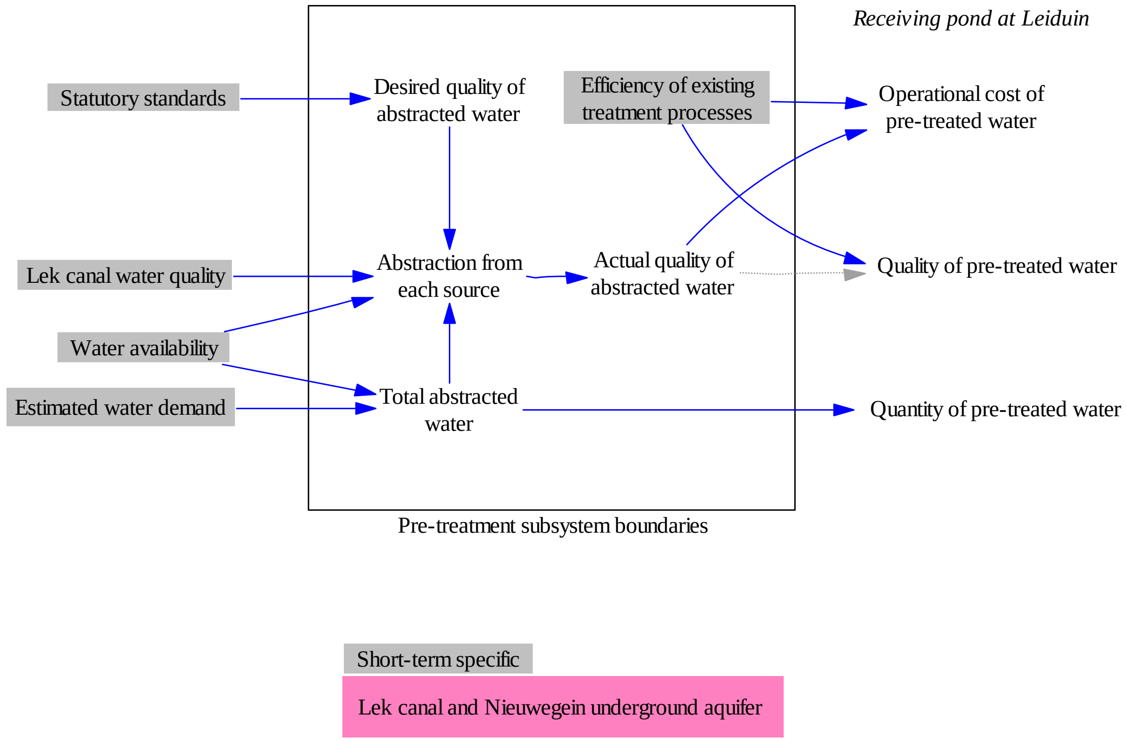

FIGURE A - 5 FIGURE 26 CONCEPTUALIZATION OF THE PRE-TREATMENT SYSTEM OF THE *LEIDUIN CHAIN* (PT-L) : MAIN INPUTS AND MONITORED OUTPUTS

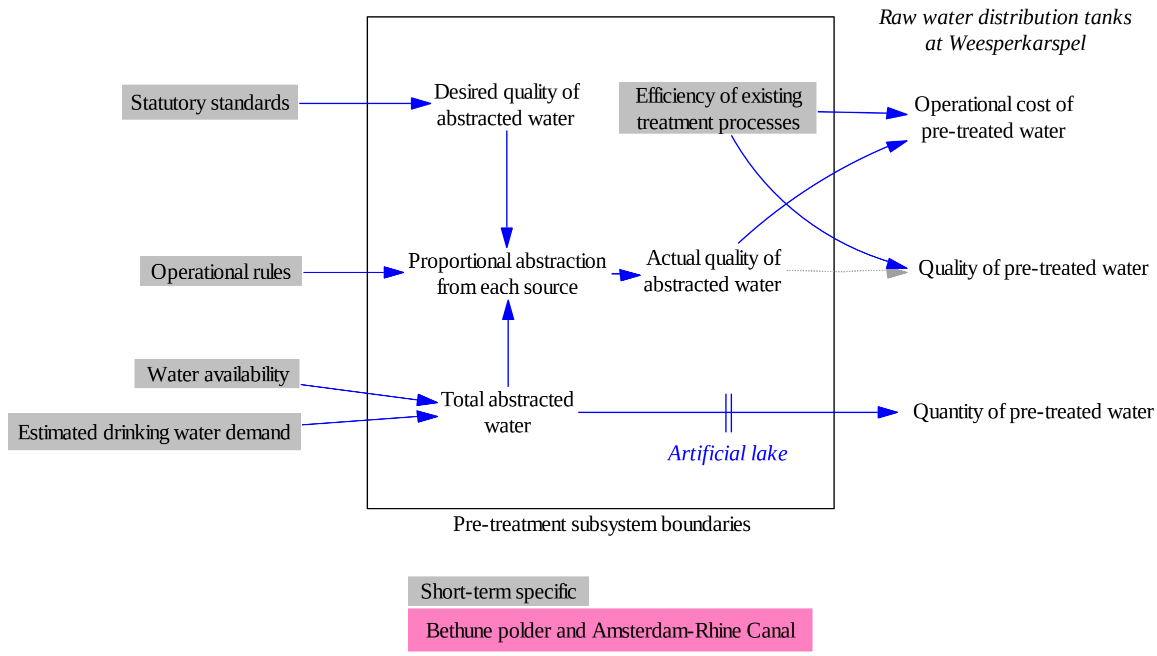

FIGURE A - 6 FIGURE 27 CONCEPTUALIZATION OF THE PRE-TREATMENT SYSTEM OF THE *WEESPERKARSPEL CHAIN* (PT-W): MAIN INPUTS AND MONITORED OUTPUTS